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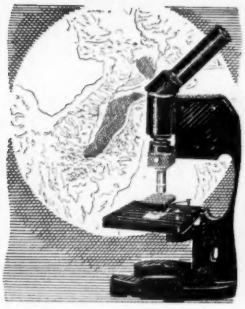

Surface Tension of Pure Liquid Iron, Cobalt, and Nickel at 1550° C

By Paul Kozakevitch and Georges Urbain

SYNOPSIS

The surface tension of pure liquid iron, cobalt, and nickel has been measured at 1550° C by the sessile drop method. By control of the atmosphere (partial pressure of oxygen less than 10^{-15} atm) and use of pure oxide refractories, it was possible to obtain less than 0·001% dissolved oxygen in the drop. The 'capillary constant' of iron, $a^2 = \gamma/gd$, was found to be 26·0 mm² and the surface tension (density 7·2) $\gamma = 1835$ dyn/cm. For cobalt $a^2 = 25·3$ mm² and $\gamma = 1936$ dyn/cm (density 7·8). For nickel $a^2 = 25·8$ mm² and $\gamma = 1924$ dyn/cm (density 7·6). 1331

Introduction

IT HAS RECENTLY BEEN SHOWN that the considerable lowering of the surface tension of liquid iron and iron–carbon alloys by sulphur[1] and oxygen[2] may be of vital importance in such varied phenomena as iron emulsification (iron shot) in slags[3] and formation of nodular graphite.[2, 4] An exact knowledge of the surface tension of pure liquid iron is of course necessary if the lowering action of very small quantities of surface-active substances is to be measured. Unfortunately, even the most recent data vary between 1370 dyn/cm in 1949 by Becker, Harders, and Kornfeld,[5] 1560 dyn/cm in 1953 by Kingery and Humenik[6] and 1720 dyn/cm by Halden and Kingery[2] in 1955. It is clear that further measurements are desirable. Only one series of measurements on nickel[6] is known to the present authors and they are not aware of any measurement on cobalt. These metals were therefore included in the present work.

The main features of the present work are: preparation of metal samples in various ways, control of the oxygen pressure in the furnace (we were able to go as low as 10^{-15} atm) and use of refractories made of those pure oxides which would not react significantly with iron, cobalt, and nickel in equilibrium with the furnace atmosphere. All the results of experimentally successful runs have been reported rather than selected or mean values, so as to permit a better evaluation of the dispersion.

EXPERIMENTAL

The sessile drop method was used, but the apparatus previously described[1] has been improved in many ways. The drop (approximately 1·9 g) and its support (pure Al_2O_3, CaO, BeO, ZrO_2, or ThO_2) were placed in a gas-tight vertical alumina tube, heated in a resistance furnace. The atmosphere was either best quality argon, dried with magnesium perchlorate and purified with titanium at 850° C, or hydrogen purified in a Deoxo apparatus (catalysis) and thoroughly dried with perchlorate. To remove all the oxygen adsorbed on the refractories and to reduce the oxide which might be present on the surface of the cold metal, preheating (up to 1450° C) was always operated in a flow of pure dry hydrogen. The image of the liquid drop was then formed on a photographic film by a horizontal beam of X-rays passing through the furnace. Four negatives were taken, the drop being turned 90° each time with a special device. A modification of Dorsey's method previously described[1] was used for measurements and calculation.

The beam of X-rays was generated by a medical-type tube with rotating tungsten target working at 90–100 kV. At 8 mA the exposure time necessary to get a good contrast was approximately 15 s. Photographic enlargements on high-contrast plates were used for measurements, the absolute dimensions of the drop being determined by comparison with the image of a steel ball, whose diameter was exactly known.

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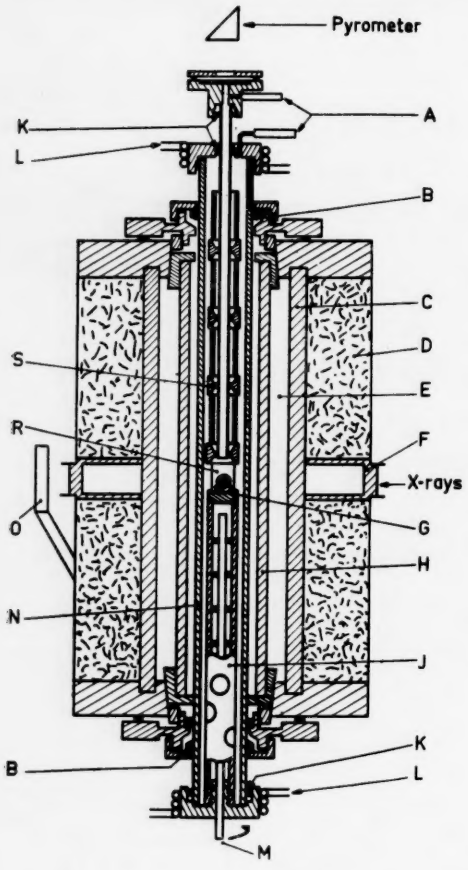

A—gas inlet
B—tight joint
C—graphite tube
D—coke
E—carbon black
F—graphite
G—drop support
H—carbon resistor
J—refractory stand
K—special elastic joint
L—water cooling
M—gas outlet to vacuum pump
N—alumina tube
O—photographic film
R—alumina crucible
S—shields

Fig. 1—Carbon resistance furnace

The carbon resistance furnace is represented diagrammatically in Fig. 1. Special elastic joints ensured gas-tightness of the whole system and allowed the drop to be turned together with its support. The temperature was measured with an optical Ribaud pyrometer, the prism correction being taken into account. The contour of the drop could not be seen, an indication that black-body conditions were closely satisfied. All measurements were made at 1550 $\pm$ 5° C under 1 atm of argon or hydrogen and the evacuation with a rotary oil pump served chiefly to remove rapidly the bulk of the air and to check the gas-tightness before and after each run.

The temperature coefficient of the surface tension is usually very small. Becker, Harders, and Kornfeld[5] were unable to detect any significant variation of γ on iron drops between 1530° and 1700° C. The standard deviation for our own data being only a little less than 1% (see below), it was judged useless to vary the temperature.

Hydrogen, when thoroughly dried with magnesium perchlorate, contains about 2μg water per litre.[7] At 1550° C this gives 10^{-18} atm of oxygen. A direct test indicated that probably the actual vapour pressure was close enough to the anticipated value. In any case, it is considered that the oxygen pressure at 1550° C was less than 10^{-15} atm. The test consisted in a selective oxidation at 1200° C of a Cr–Ni alloy which was placed in the furnace and submitted to the usual cycle of operations. A microscopic examination of the surface by the method of Moreau and Benard[8] then permitted one to estimate roughly the water-vapour content of the gas. The test, while reliable in hydrogen with which Moreau and Benard worked, is probably much less so in argon, since oxidation by traces of free oxygen may be kinetically different from oxidation by hydrogen–water mixtures. Under normal conditions, but at 1200° C, the test indicated 10^{-15} atm oxygen in the argon. The oxygen pressure was not so good when the furnace was evacuated at high temperature. It was bad when preheating was done under argon. Maintaining the hydrogen flow was therefore essential during the period when the refractories were giving off adsorbed oxygen.

Good supports for the drops should be made of very pure oxides which have little tendency to react with liquid iron, cobalt, or nickel. In addition the supports should have a well ground surface of a fine-grain, porous refractory, because the apparent contact angle (if greater than 90°) is much more favourable on a rough (granular) surface than on a perfectly smooth one,[9] and this is essential for the method of measurement used here. Al_2O_3, CaO, ZrO_2 stabilized with lime, BeO, and ThO_2 were used. The upper face of the cylindrical support bearing the drop was slightly concave, chiefly to make sure that the drop always occupied the same position in the tube and to avoid the necessity of keeping this face perfectly horizontal during the run. The X-rays easily penetrate through the refractories except in the case of ZrO_2 and ThO_2, so these had their upper faces almost plane so as to permit measurements with ϕ angles up to 135° (see below). The contact angle on rough surfaces was usually greater than 140°.

Fine-grain alumina (99–99·5% Al_2O_3, $<$ 0·05% silica) was used, while lime was prepared from the purest calcium metal of the Commissariat à l'Energie Atomique. The general manufacturing technique was that of the Department of R. Caillat at the C.E.A., somewhat modified in this laboratory by M. Olette and T. M. Poilleux. From a purely thermodynamic point of view, ThO_2 is possibly the best material. Unfortunately, the surfaces of the sintered ThO_2 supports were too smooth; even when they had been ground with coarse alumina, favourable contact angles could be maintained for only a few minutes after melting. The angle then rapidly diminished and finally remained stationary at 110°. Little use was therefore made of these supports. To avoid slagging at the contact of the supports with the alumina crucible (Fig. 1) a thin molybdenum sheet was interposed.

The starting material for preparation of the iron samples was pure carbonyl iron. To remove carbon, this iron was treated for 16 h at 1200° C and 2–3 h at 760° C with wet hydrogen. The water vapour was

then removed in vacuum and the iron thoroughly deoxidized (and desulphurized) with a very pure dry hydrogen (10 h at 1200° C and 5 h at 760° C). The resulting sintered product usually contained less than 0·001% carbon, not more than 0·0008% oxygen, while sulphur was well below the limits of the combustion method. Impurities other than carbon, oxygen, and sulphur, were: $N_2 < 0·0005\%$, Mn 0·00004–0·0007%, Ni 0·004–0·015%, As 0·0001%, Al 0·001%, Si 0·001%, Cu 0·0003%, Ag 0·0001%, Mg 0·0002%; Cr, Co, Mo, V, Sn, Pb not detectable; Ti, Ca, Na traces below the limit of a quantitative determination. The methods employed in the analysis were: semi-microchemical, activation followed by detection of radio-isotopes, and spectrographic on solutions. The only noticeable impurity was nickel, which reached 0·015% in the most contaminated samples. But the surface tension of nickel is very high (see below and also reference 10), so its presence cannot be harmful. A few samples of less thoroughly deoxidized iron (0·008 and 0·005% oxygen) and of iron with additions of cerium (0·092%) or zirconium (0·21%) were also used. In the latter cases, 400 g of the purified sintered iron were melted under high vacuum (10^{-5} mm of mercury, BeO crucible), the pure alloying element was added and the resulting alloy was poured under vacuum into a copper mould. The results for these are listed at the bottom of Table I.

Cobalt and nickel samples were prepared from spectrographically standardized metal rods.* Cobalt contained Si $\leqslant$ 0·0002%, Fe $\leqslant$ 0·0005%, Al $\leqslant$ 0·0001%, Ca not measurable, Mg $\leqslant$ 0·0001%, and Cu $\leqslant$ 0·0001%. Nickel contained Fe $\leqslant$ 0·001%, Ca not measurable, Cu $\leqslant$ 0·0002%, Mg $\leqslant$ 0·0001%, and Si $\leqslant$ 0·0001%. The two metals exhibited no lines of the following elements: Ag, As, Au, Ba, Bi, Cr, Cd, K, Li, Mn, Mo, Na, Pb, Rb, Sb, Sn, Ti, V, W, Zn, Zr. Cobalt contained no nickel, and nickel was free from cobalt. The sulphur content of the cobalt and nickel rods was well below the limit of the combustion method, but the total oxygen content was rather high: 0·006% in cobalt and 0·041% in nickel. Each sample was therefore treated for 4–5 h with hydrogen, before taking any measurement.

Runs which appeared to be satisfactory during the operation were discarded only in the following cases: leak in the tube detected after the run, abnormal appearance of the cold drop (spots on its bright surface), or visible dissymmetry of the drop on the photograph. No measurement was ever made on drops originating from discarded runs and no measurement on experimentally valid drops was discarded, whatever the resulting value of the surface tension.

METHOD OF CALCULATION

The method of Dorsey[11] was followed since the authors know of no certain method of locating exactly the equatorial plane on the photographic image of a drop†). On the one hand, AB, the equatorial diameter (Fig. 2) was measured, and on the other hand OM, the distance to the top of the drop from a point O on the axis selected so as to be at the apex of a known angle whose sides are tangential, to the meridional contour.

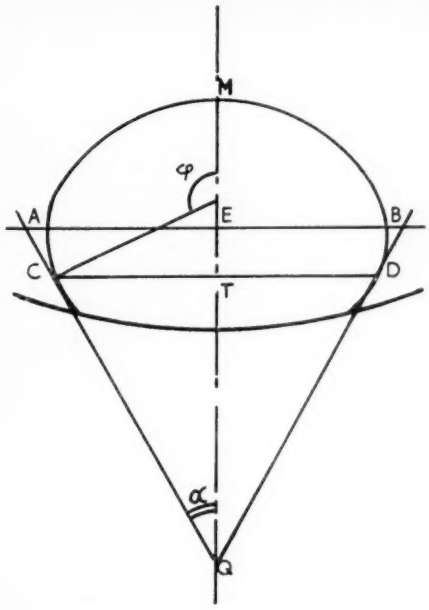

Fig. 2—Diagram of image of liquid drop

Dorsey used a 90° angle and placed its apex above the top of the drop. But any angle may be used, and, if the shape of the drop permits, it may be placed below the drop just as well as above. Angles of 90° and 60° were used here, and, whenever possible, they were placed in both positions.

The measurements were taken on enlarged images, illuminated through the window of a viewer. The emulsion side of the plate was placed in contact with a grating engraved on a glass plate and consisting of two perpendicular sets of parallel straight lines, the centre line of the vertical set bisecting two angles, one of 90° and the other of 60°. The procedure was to make the centre line coincide with the axis of symmetry of the meridional section (thus providing a check on the symmetry) and to bring both sides of one of the angles in contact with the contour. The distance from the apex of the angle to the top of the drop and the length of the equatorial diameter were then read off the image. The coarse grain of the X-ray film did not allow perfectly sharp enlargements to be produced, and we believe this to be the principal drawback of the method. On making several (four to ten) adjustments and readings, mean values accurate to a tenth of a millimetre could however be obtained.

* Supplied by Johnson, Matthey and Co., Ltd.

† The exact position of the equatorial plane may easily be determined on non-luminous drops whose surface has a sufficiently high reflecting power, but this is no longer possible when only the contour of the drop is available (an X-ray photograph), chiefly because the equatorial plane is not a plane of symmetry. It thus becomes difficult to measure with precision the parameter commonly used in the sessile drop method (the distance between the top of the drop and the equatorial plane).

Table I

CAPILLARY CONSTANT OF PURE LIQUID IRON AT 1550° C

Run Number	Deoxidizer	Initial Total Oxygen (analysis %)	Gas	Support	$a^2 = \gamma/gd$ mm²				a^2 Average Value
					A	*B*	*C*	*D*	
819	None	0·008	Argon	Al_2O_3	26·00	25·80	26·08	25·80	25·92
818	,,	,,	,,	,,	25·93	25·89	26·05	26·03	25·98
817	,,	0·005	,,	,,	25·90	26·26	25·67	25·90	25·93
829	,,	0·0008	,,	,,	25·80	25·74	25·26*	25·98	25·70
828	,,	,,	,,	,,	25·83*	26·30*	25·52*	...	25·88
834	,,	,,	,,	CaO	26·28	25·72	25·89	25·96	25·96
835	,,	,,	,,	,,	25·96	26·19	26·25	...	26·13
843	,,	,,	Hydrogen	,,	26·04	26·28	25·69	25·75	25·94
837	,,	,,	,,	Al_2O_3	25·87	26·01	25·94	26·01	25·96
838	,,	,,	,,	,,	26·01	26·01	25·87	26·51	26·11
844	,,	,,	,,	,,	26·16	26·12	25·82	26·09	26·10
851	,,	,,	,,	,,	26·10	25·98	25·77	25·77	25·91
840	,,	,,	,,	BeO	26·34	25·90	... †	... †	26·11
841	,,	,,	,,	ThO_2	26·06	25·81	... †	... †	25·94
861	,,	,,	,,	,,	25·98‡	25·81‡	25·90‡	25·98‡	25·92
862	,,	,,	,,	,,	26·07‡	26·16‡	26·07‡	26·07‡	26·09
839	0·092% Ce	0·003	,,	Al_2O_3	25·98	26·01	25·49	25·72	25·80
824	0·003% Ce	0·002	Argon	,,	...	26·10	25·83	...	25·97
820	0·21% Zr	0·001	,,	,,	25·75	25·36	26·15	25·77	25·76
854	,,	,,	Hydrogen	,,	... §	... §	26·19‖	25·98‖	26·09
821	,,	,,	Argon	ZrO_2	25·96	26·11	25·78	25·78	25·91
826	,,	,,	,,	,,	25·68	25·96	25·75	...	25·80

* Image of poor symmetry
† Contact angle did not permit use of $\phi = 120°$ and 135° owing to smooth surface of sintered oxide
‡ Sintered oxide with a layer of ThO_2 powder added: good contact angle
§ Four unusable images of an elongated drop which gradually becomes less assymetrical
‖ Fifth and sixth photograph of the drop number 854, now sufficiently symmetrical

A further drawback being the possible transmission of X-rays through an infinitesimal thickness of molten metal at the edge of the sessile drop, one might ask whether it would not be better to use visible rays. This would require, however, a horizontal tube with glass windows[2, 5, 6] in which a vacuum would have to be maintained since the refractive index of the gas varies with temperature along the axis of the tube. Chatel,[13] in this laboratory, adopted Kingery's technique[2, 6] but it has been felt that the advantage of a better definition of the drop contour is largely counterbalanced by several other difficulties and by the impossibility of turning the drop.

The drop contour changes slightly with 90° rotation, probably because the movement is not smooth enough. It is therefore believed that the four images of each drop (see Experimental section) are to be considered as images of separate drops of identical composition. This is supported by the fact that the dispersion of the results on four images of the same drop (*A*, *B*, *C*, and *D*, horizontal lines, Table I) is almost identical with that observed on actually different drops (vertical columns).

Let *C* and *D* be the points of tangency of the sides of the angle *COD* with the contour (Fig. 2, apex below the top of the drop). Let *E* be the point of intersection of the axis with the normal to the contour in *C*, and let:

$$\angle COD = 2a,\ \angle MEC = \phi,\ AB = 2r,\ OM = h$$

$$\text{then } \phi = \frac{\pi}{2} + a,\ OM = OT + TM = -TC\tan\phi + TM \text{ and } \frac{h}{r} = -\frac{TC}{r}\tan\phi + \frac{TM}{r}$$

If g, d, b, and γ are defined respectively as the acceleration due to gravity, the specific mass of the drop, its radius of curvature at the top, and its surface tension, and if all are expressed in c.g.s. units, the shape of the drop depends upon the parameter

$$\beta = \frac{gdb^2}{\gamma} = \frac{b^2}{a^2}, \text{ where } a^2 = \frac{\gamma}{gd} \text{ is the 'capillary constant.'}$$

The tables of Bashforth and Adams[12] give the ratio TC/b and TM/b as functions of β and ϕ as well as the ratio $p = r/b$ as a function of β. From these, four tables have been prepared for $\phi = 45°$, 60°, 120°, and 135°, and these give the ratios $u = h/r$ as a function of β for values of β ranging from 0 to 5·0 at intervals of 0·1.[13] By means of interpolation, the tables yield four values of β corresponding to the four measured values of u.

Since the errors vary widely with β and ϕ, weights were assigned to the corresponding values of β by means of the method developed in this laboratory by Chatel.[13] For most of the data, which correspond to β values in the vicinity of 0·9, the weights used were respectively 10, 12, 23, and 35 for $\phi = 45°$, 60°, 120°, and 135°. These figures make it clear that, for the results to be reliable, it was essential that it should be possible to use the angles of 120° and 135°. It should be pointed out that Dorsey's original method, which is limited to the use of $\phi = 45°$, produced very scattered results on our drops.

Finally, a fifth table was prepared giving the values of the ratio $p = r/b$ as a function of β; p was determined by interpolation and b followed. β and b being known, only d must be known to apply the formula $\gamma = gdb^2/\beta$. The value of d, if no reliable data are

available, may be determined from the volume of the drop as measured on the enlargement.[1, 13]

The scatter of the results obtained on the four negatives of each drop is much smaller than in our previous work on Fe–C–S alloys (compare Table I of the present work with Table VII of reference 1).[1] Better atmospheres, a better X-ray tube, and the use of pure oxides for drop supports are probably responsible for this improvement.

PRESENTATION AND DISCUSSION OF THE RESULTS

The results of all experimentally successful runs on pure iron and on some samples containing deoxidizers (Zr or Ce) are given in Table I. Usually, the results on the four negatives A, B, C, and D (see Experimental section) are given, but in a few cases some photographic defect of the negative made the measurement impossible.

Because the tables of Bashforth and Adams yield directly the values of $a^2 = \gamma/gd$ (see above for method of calculation) it was preferred to tabulate values of a^2 (in square millimetres) rather than values of γ since the former are independent of the existing doubtful values of the density.

The distribution of the experimental results has been tested and found to be random (77 measurements, average value $a^2 = 25{\cdot}94$ mm^2, standard deviation 0·22). The graphic adjustment is very good, the points following closely the normal Henry linear relationship. It may however be pointed out that the standard deviations are somewhat higher for the data of columns B, C, and D (0·22, 0·25, and 0·20 respectively) than for those of column A (0·16). This is probably due to the fact that the gas (argon or hydrogen), which initially fills the spaces between the grains of the support surface, is gradually expelled by the liquid metal of the drop until the appropriate equilibrium contact angle is attained. The symmetry of the contour, which gives the values of a^2, is then possibly affected by the slight movement of the drop. The mean values remain almost the same (25·99, 25·98, 25·85, and 25·94 for columns A, B, C, and D respectively), but the deviations become somewhat larger. A few of the highest deviations are certainly due to a non-uniform distribution of grain in the negative near the top of the drop.

No significant deviation of a^2 values depending upon known factors varying from one run to the other could be detected (see, for instance, the average a^2 values in Table I). These known factors are:

(a) Total oxygen content of the metal as determined before the run, that is, before preheating in hydrogen (0·0008% in most runs, 0·005% in run 817, 0·008% in runs 818 and 819, and between 0·001 and 0·003% in the presence of deoxidizers).

(b) Nature of the atmosphere (argon with 10^{-15} atm and hydrogen with less than 10^{-15} atm oxygen).

(c) Nature of the support material: Al_2O_3 with $\Delta G^\circ = -173$ kcal per mole of oxygen at 1550° C, CaO with $\Delta G^\circ = -210$ kcal and boiling point of the resulting metal approximately 1500° C, BeO with $\Delta G^\circ = -210$ kcal and boiling point of the resulting metal approximately 1540° C, ZrO_2 with $\Delta G^\circ = -180$ kcal, and ThO_2 with $\Delta G^\circ = -218$ kcal, compared with $\Delta G^\circ = -64$ kcal for FeO.

(d) Deoxidizers: Ce with Ce_2O_3 $\Delta G^\circ = -210$ kcal per mole oxygen at 1550° C and Zr with ZrO_2 $\Delta G^\circ = -180$ kcal.

It is however not altogether certain that the deoxidizers used here do not slightly lower the surface tension. In any case, the deviations which might be caused by the deoxidizers are less than 1% and their existence can hardly be proved with our present technique.

Four interpretations could be proposed for this lack of any pronounced dependence of a^2 on factors a to d:

(i) The varying concentrations of surface active substances, most probably [O] and [S], are too small to affect noticeably the results obtained by the present method. In this case, the surface tension of pure liquid iron was actually measured.

(ii) All results are uniformly affected by the surface active substances [S] and/or [O] actually present.

(iii) In each case, the effects of different impurities compensate each other. For instance, the rise of a^2 due to diminished oxygen content in the presence of hydrogen or zirconium as compared with argon is exactly counteracted by a hypothetical lowering action by hydrogen or zirconium.

(iv) The concentrations of known impurities being very small, the values of a^2 are uniformly affected by some unknown but very active substance.

Point (iv) would apply to any property depending strongly upon presence of certain impurities. In the case of surface tension it simply means that the result of any measurement may, in principle, be too low, for traces of impurities can have a noticeable effect on the surface tension only if they lower it. It may be added that no factor is known which would act in the opposite direction, provided measurements are made correctly and on symmetrical drops only.

Point (iii) is really highly improbable, and so it is only necessary to consider the possible oxygen and sulphur contents of the iron drops under argon or hydrogen and in contact with different support materials. It should, of course, be recognized that no macro- or microscopic suspension can be surface-active. Thus, only 'dissolved' oxygen may alter the surface tension of iron, but not the oxygen-bearing inclusions suspended in the liquid metal.

The drops of pure iron with no deoxidizers usually contain, when analysed after the run, about 0·002% total oxygen, but the limit of the hot extraction method, when applied to a 1·7-g sample (drop weight about 1·9 g) is 0·001% oxygen, corresponding to approximately 0·02 cm^3 CO. Thus, the direct drop analysis gives little more than a rough indication: the total oxygen content of the metal after the run lies between 0·001 and 0·003%.* It follows that the iron samples with higher initial oxygen lose a part of it, while the most pure ones possibly pick it up during (or after) the run. Point (ii) might therefore apply (uniform contamination with approximately 0·002% oxygen), if this oxygen is really 'dissolved' in the liquid iron and not picked up after the run.

The oxygen content in equilibrium with the argon atmosphere should be about 0·0001% and still less with the hydrogen. The preheating was conducted in hydrogen, so that no oxygen could have been picked

* Oxygen determinations before the run were made on 20-g samples.

Table II

CAPILLARY CONSTANTS OF PURE LIQUID COBALT AND NICKEL AT 1550° C

COBALT						
Run Number	Gas	Support	$a^2 = \gamma/gd$ mm²			
			A	*B*	*C*	*D*
845	Hydrogen	Al_2O_3	25·35	25·25	25·09	25·11
846	,,	,,	25·35	25·37	25·35	25·19
852	,,	,,	... *	25·50*	25·59*	25·50*
863	,,	ZrO_2	25·40	25·40	25·28	25·40
870	,,	ThO_2†	25·16	25·22	25·40	25·16

NICKEL						
Run Number	Gas	Support	$a^2 = \gamma/gd$ mm²			
			A	*B*	*C*	*D*
847	Hydrogen	Al_2O_3	25·77	25·77	25·59	25·49
848	,,	,,	26·07	25·77	26·07	25·77
868	,,	ThO_2†	... ‡	25·81	25·40	26·13
869	Argon	ThO_2†	25·67	25·63	26·07	25·75

* Image of poor symmetry
† Sintered oxide with a layer of ThO_2 powder added: excellent contact angle
‡ Double contour, moving drop

up from the gas. Aluminum was determined in drops 837 and 838 (hydrogen, alumina support) and found to be approximately 0·005%. From the results of Gokcen and Chipman,[14] this corresponds to approximately 0·001% oxygen in the melt, so that the alumina support could have been responsible for over a half of the quantity actually found. This is certainly not the case with ZrO_2 and ThO_2.

Melts with cerium and zirconium should contain little dissolved oxygen: possibly 0·00002% in the case of zirconium.* But a^2 values remain unaffected. Thus, it must be concluded that either the variations in dissolved oxygen contents between approximately 0·001 and 0·00002% do not alter the surface tension appreciably or that the bulk of the total oxygen found after the run is due not to dissolved matter but to a contamination by oxygen-bearing impurities suspended in the liquid metal. In either case the measured average value of a^2 may be considered as the minimum ' capillary constant ' of pure liquid iron at 1550° C, so it does not matter which of these two possibilities is right. The second is however supported by the fact that fine particles of support material were always rather numerous in the body of the metal near the bottom of the drop. This layer was ground away before analysis, but even then fine particles of the abrasive material were always found imbedded in the drop. It may also be pointed out that iron samples with deoxidizers, as analysed before the run, always gave somewhat higher total oxygen contents than the unmelted pure iron: 0·001% with 0·21% zirconium and 0·003% with 0·092% cerium. It is believed that in these cases the bulk of the oxygen was also due to suspended matter, originating from deoxidation of the molten metal with cerium or zirconium or from a reaction between deoxidizers and the crucible during the vacuum fusion.

It has been said (Experimental section), that the initial sulphur content of our iron samples was well below the limits of the combustion method. A possible source of this contaminant might have been the titanium in the furnace for argon purification, as this metal contained some 0·02% sulphur. If so, the results in hydrogen ought to have been higher than in argon, but this is not the case. Another source of sulphur might have been the alumina tube of the furnace, but this is most improbable: the tube was always heated for several hours before use in pure dry hydrogen at 1550° C. The iron samples contained practically no nitrogen ($< 0·0005\%$), but, because of the preheating (up to 1450° C) under hydrogen, they probably contained hydrogen even when the run was conducted under argon. These remarks also apply to the measurements on cobalt and nickel.

It is thus believed that all the data of Table I can be used to calculate the mean value (low estimate) of the capillary constant of pure liquid iron at 1550° C, so that $a^2 = 25·94$ mm² or:

$$a^2 = \gamma/gd = 25·9 \text{ mm}^2$$

The standard deviation is 0·22 and the total number of measurements 77. As stated above, however, the standard deviations in columns *B*, *C*, and *D* are somewhat higher than in column *A*, possibly because

* 0·00002 is the anticipated activity of oxygen in presence of about 0·2% zirconium. The measured oxygen content may well be somewhat higher[15] but we do not think that the difference can be very large, say twenty times or more. Such a lowering of activity would probably be equivalent to formation of a new molecular species, but this would then be ZrO_2 which is probably insoluble in iron.

Table III

PHYSICAL PROPERTIES OF LIQUID IRON, COBALT, AND NICKEL AT 1550° C COMPARED WITH THOSE OF COPPER AT 1200° C

Metal	Atomic Weight	Density	Atomic Volume, cm^3	γ, dyn/cm	a^2, mm^2
Iron	55·85	7·2	7·75	1835	26·0
Cobalt	58·94	7·8	7·55	1936	25·3
Nickel	58·69	7·6	7·72	1924	25·8
Copper	63·54	8·1	7·84	1300	16·4

of the slight movement of the drop which may occur when the liquid metal begins to expel argon or hydrogen from the rough surface of the support. It may be reasonable therefore to take account only of those drops (column A) which have spent least time in contact with the support. The mean value becomes then 25·99 mm^2 or:

$$a^2 = \gamma/gd = 26{\cdot}0 \text{ mm}^2$$

The standard deviation is 0·16 and twenty measurements were used. Although these two values are practically identical, we prefer the second. It is felt (see above), that this value corresponds to an iron with less than 0·001% dissolved oxygen, the actual content varying perhaps between 0·0001 and 0·00002%. The above capillary constant is *half* the capillary constant used with the capillary rise method $2\gamma/gd = hr$.

The density of pure liquid iron at 1550° C is 7·21 according to Benedicks, Ericsson, and Ericson[16] and 7·01 according to Stott and Rendall.[17] Our estimate (drop volume) is 7·2. It is clear that further density measurements are desirable. From a tentative value of 7·2, the surface tension of pure liquid iron at 1550° C becomes, as a minimum value:

$$\gamma = 1835 \text{ dyn/cm}$$

with standard deviation 15 dyn/cm and number of measurements twenty. This value is higher than the most recent result of Halden and Kingery[2] and our own previous estimate of 1700–1800 dyn/cm based on an anticipated correction for the effect of 0·005% sulphur.

The results for cobalt and nickel are presented in Table II. The mean value of a^2 for nickel is 25·8 mm^2 (standard deviation 0·22, number of measurements fifteen). This figure is almost identical with that for iron. For cobalt a^2 is slightly lower: 25·3 mm^2 with standard deviation 0·14 and number of measurements nineteen. No density measurements on liquid cobalt are known to us. Our rough estimate at 1550° C is 7·8 (drop volume). Two series of measurements on liquid nickel are available[16, 18] and a slight extrapolation of these gives 7·65 and 7·56. Tentative values to be used for the calculation of surface tension are therefore 7·8 for cobalt and 7·6 for nickel. This gives at 1550° C $\gamma = 1936$ dyn/cm for cobalt and 1924 dyn/cm for nickel. As far as the authors are aware, these surface tensions (as well as that for iron) are the highest ever measured on any known substance.

In Table III a few physical properties of liquid iron, cobalt, and nickel at 1550° C are listed to be compared to those of copper at 1200° C.[1] The most characteristic feature of this table is the sudden drop of the surface tension when one passes from the metals of the iron group to copper. It may also be noticed that, for the elements of the iron group, the surface tension increases with increasing density and that the inverse relationship between surface tension and atomic volume found by Atterton and Hoar[19] seems to be valid for all four metals listed. However, in the iron group, the surface tension values follow more closely the variations of the atomic weights than those of the atomic volume (see Table III).

Acknowledgments

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ANDREW CARNEGIE SCHOLARSHIP RESEARCH REPORT

Correlation of Tensile Properties with Microstructure for Some 3% Nickel Steels

By J. P. Hugo, B.Sc.(Eng.)., Ph.D., A.I.M., and J. H. Woodhead, B.Met.

SYNOPSIS

The relationships between the isothermal transformation temperature and the tensile properties of three 3% nickel steels have been investigated. In the pearlite range, confirmation was obtained for the theory that the interlamellar spacing of pearlite is inversely proportional to the degree of undercooling. Consequently, by relating all properties to the degree of undercooling rather than to the transformation temperature, the effect of interlamellar spacing has been determined. For pearlitic steels it has been shown that after allowing for the effects of pro-eutectoid ferrite, the strength properties are linearly dependent on the square root of the interlamellar spacing. Such a relationship is in accordance with dislocation theory. The results may also be related empirically to the logarithm of the interlamellar spacing. No simple relationship appears to exist for the strength properties of bainitic steels nor for the ductility results for the steels in either pearlitic or bainitic states. 1340

THE RELATIONSHIPS between the tensile properties and the microstructure of steels are of considerable interest from both the theoretical and practical points of view. Qualitatively these relationships are well known but the quantitative aspects of the problem have so far received little attention. Gensamer and his co-workers[1, 2] have studied a number of plain carbon steels of approximately eutectoid composition but there appears to have been no similar work reported for the hypo-eutectoid steels. The authors therefore set out to investigate the properties of hypo-eutectoid steels in relation to their microstructures. A re-examination of the eutectoid steels also seemed desirable because not only do they provide a standard of comparison for the lower carbon steels but also because a careful survey of Gensamer's work[2] showed that, in many cases, the experimental results deviated considerably and systematically from the curves presented.

It is clear that the tensile properties of steels having pearlitic microstructures will depend mainly on the interlamellar spacing of the pearlite. Consequently it is desirable that this spacing should be as nearly constant as possible throughout any specimens used in the investigation. Pellissier *et al.*[3] have shown that the interlamellar spacing of pearlite is substantially constant when the steel is transformed at a constant sub-critical temperature. The present investigation was therefore restricted to isothermally transformed steels, as such a restriction had two important advantages when pearlitic steels were being studied: (*a*) the interlamellar spacing was constant throughout the specimen, and (*b*) the temperature of transformation provided an accurately known variable to which the properties of the materials could be related.

The method used for the determination of the interlamellar spacing was laborious and liable to appreciable error. As a result, an unnecessary uncertainty would be introduced into any attempt to correlate directly the tensile properties and the interlamellar spacing. Consequently the relationship between the interlamellar spacing and the transformation temperature was determined. Once this had been done, the tensile properties could be related to the accurately known transformation temperature and hence indirectly to the interlamellar spacing. This indirect approach had also the advantage that the interlamellar spacing could be estimated in cases where the pearlite was too fine for direct measurement.

The investigation was not confined to steels having pearlitic microstructures but a eutectoid steel was studied after transformation in the bainite range. Unfortunately the hypo-eutectoid steels used could not be transformed isothermally in the bainite range and therefore the tensile properties of steels having microstructures consisting of bainite and ferrite were not investigated. The properties of bainitic steels were considered to be of considerable interest because Gensamer *et al.*[2] quote results for such steels but fail to comment on some unexpected and anomalous behaviour.

All test results are reported in terms of 'true' stresses and logarithmic strains because the authors are convinced that such units are not only of greater fundamental significance but also provide more immediately useful information than do the customary nominal stress and linear strain units.

CHOICE OF MATERIALS

At the beginning of this work the authors hoped to use plain carbon steels low in manganese, silicon, sulphur, and phosphorus, and free from chromium, nickel, copper, and other alloying elements. A series of such steels was available and it was considered

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that their relative purity would make easier the interpretation of the results of the investigation. It was also considered desirable to use the largest specimen which could be adequately heat treated, as this would lead to the greatest accuracy in tensile testing.

Because truly isothermal transformation of the specimens was desired, it was considered necessary to investigate in some detail the quenching and transformation characteristics of any steels used. The method adopted was to record time/temperature curves during the quench to the transformation temperature. The records were obtained by cinephotography of a rapidly responding millivoltmeter to which was connected a chromel/alumel thermocouple inserted in the test specimen. These tests showed that test-pieces having an overall length of 4 in. and a parallel section 3·5 in. long by 0·262 in. dia. could not be transformed isothermally at temperatures below about 650° C even though austenitizing was carried out in salt to avoid scaling, and the specimens were transferred to an intermediate lead bath at about 725° C to reduce the temperature interval of the final quench. Typical time/temperature curves are shown in Fig. 1, in which the behaviour of a eutectoid steel is compared with that of a steel which undergoes no transformation in the times considered. These results conflict seriously with those reported by Gensamer.[1, 2] The discrepancy may be a result of the relative purity of the steels although further work on a number of low-alloy steels makes this appear unlikely.

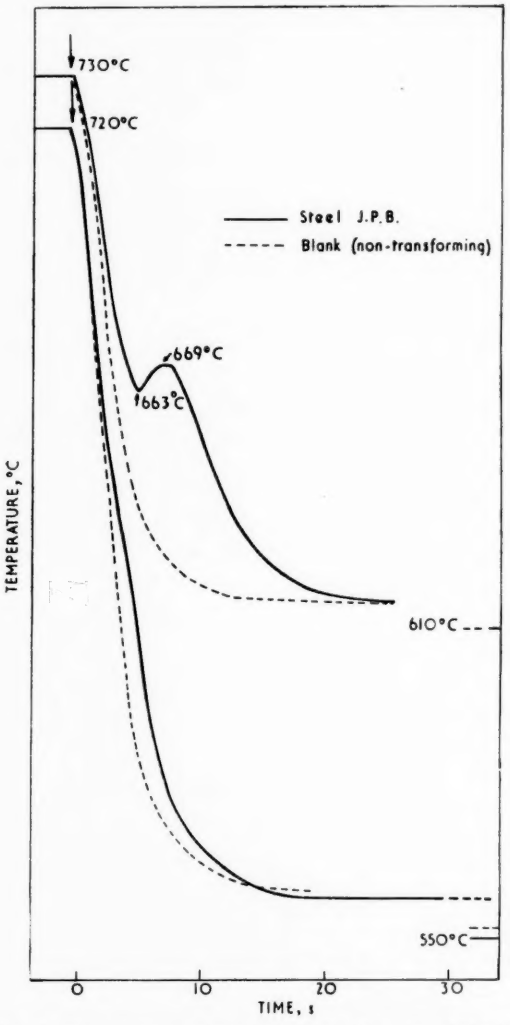

Fig. 1—Time/temperature curves for the quenching of steel J.P.8 (0·82% C) and a non-transforming steel; all specimens austenitized in salt

Table I

ANALYSIS, %, OF STEELS USED IN TESTS

Steel	C	Mn	Si	S	P	Ni	Cr	Cu	Mo
N.38	0·67	0·49	0·18	0·025	0·022	2·92	trace	nil	nil
N.36	0·55	0·46	0·18	0·034	0·021	3·04	trace	nil	nil
N.34	0·32	0·40	0·11	0·034	0·021	3·01	trace	nil	nil

To achieve satisfactory transformation characteristics it was necessary to choose an alloy steel. Chromium, manganese, and molybdenum were thought to be undesirable additions because they form stable complex carbides whose composition varies with transformation temperature in the pearlite range. Steels containing such elements would therefore show a variable partition of the alloying element between the carbide and the ferrite; under such circumstances the strength of the material would not be uniquely dependent on the amount and distribution of its microstructural constituents. Nickel was chosen as the most suitable alloying addition, as its effects are well known and it does not form a stable complex carbide.

Before satisfactory transformation characteristics were achieved it was found necessary to use steels containing 3% Ni and to reduce the size of the specimen. Accordingly a standard 0·178-in. dia. tensometer test-piece was adopted and although the choice of such a small specimen necessarily involved some loss of accuracy in the tensile test, this was minimized by extreme care in testing. The alternative of retaining a larger specimen and increasing the nickel content of the steel was rejected because this would involve excessive transformation times at the higher temperatures in the pearlite range.

The analyses of three steels made by the crucible process are given in Table I.

The steels were cast as ½-cwt ingots, forged to 1½-in. square, and finally rolled to ⅝-in. dia. bar.

Transformation Characteristics of 3% Ni Steels

Approximate isothermal transformation diagrams were determined for the steels by the micrographic method. These diagrams were obtained with the primary object of finding the times necessary for complete transformation at all temperatures in the pearlite and bainite ranges. No attempt was made to determine the transformation characteristics of the steels in the martensite range.

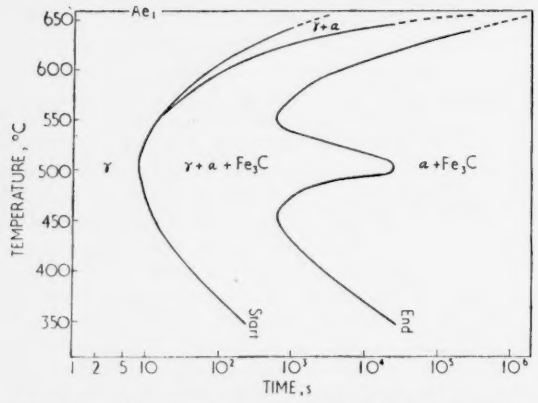

Fig. 2—Time/temperature transformation curve for steel N.38 (0·67% C, 3% Ni), austenitized in salt at 875° C

The diagrams obtained are shown in Figs. 2–4. For steels N.36 and N.34 only the pearlite range was investigated, as their minimum incubation periods are such that a tensometer specimen cannot be quenched to give isothermal transformation to bainite. Tensometer specimens of steel N.34 could only be transformed isothermally at the higher temperatures in the pearlite range, so that most of the work was done on the other two steels.

The eutectoid temperatures for the steels were determined by tempering pearlitic specimens for 24 h at various temperatures then quenching in brine. Subsequent metallographic examination revealed that in each case 660° C was the highest temperature at which austenite formation did not occur. Hence 660° C was taken as the eutectoid temperature. It is considered that this figure is accurate to ± 2° C.

General Metallographic Examination

All the steels are hypo-eutectoid, although the 0·67% C steel (N.38) yields only 6% pro-eutectoid ferrite when transformed at 620° C. The 0·55% C steel (N.36) yields 22% pro-eutectoid ferrite under the same conditions. The amount of ferrite is, of course, reduced when the steels are transformed at lower temperatures. Specimens were not transformed at temperatures above 620° C because the times required for completion of the transformation are excessive.

Most of the pearlite formed in these 3% Ni steels is typically lamellar and well-formed but there are a few scattered areas of non-lamellar ' semi-pearlite '.

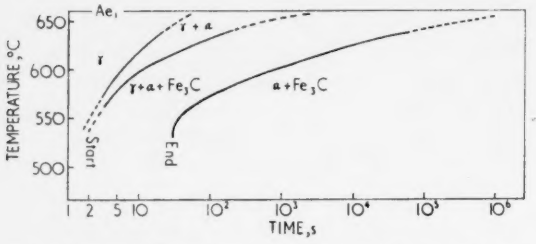

Fig. 3—Time/temperature transformation curve for steel N.36 (0·55% C, 3% Ni), austenitized in salt at 875° C

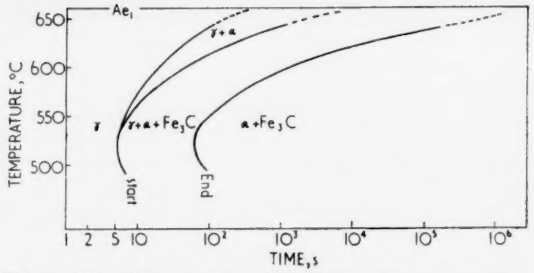

Fig. 4—Time/temperature transformation curve for steel N.34 (0·32% C, 3% Ni), austenitized in salt at 875° C

In these areas the carbides are relatively large and non-lamellar (Fig. 5) but, as Grange[4] has shown, they form directly from austenite and are not a result of tempering an initially lamellar product. It is known that for some steels the quality of the pearlite can be improved by using a higher austenitizing temperature but such a treatment had little effect on the experimental steels. High austenitizing temperatures were considered undesirable because of grain coarsening and the temperature used throughout this investigation was 875° C.

On transforming at 620° C, the 0·67% C steel (N.38) was found to have a little cementite co-precipitated with the ferrite in the grain boundaries. It will be seen later that the presence of this cementite adversely affects the ductility of a specimen transformed at 620° C. No cementite was found when steel N.38 was transformed at lower temperatures and none was found in any sample of the lower-carbon steels.

The transformation product in both steels N.38 and N.36 continued to be pearlite down to a temperature of 500° C, although a small amount of coarse, feathery bainite appeared in specimens transformed at 530° C. The amount of bainite increased as the transformation temperature was lowered, and specimens transformed at or below 450° C had fully

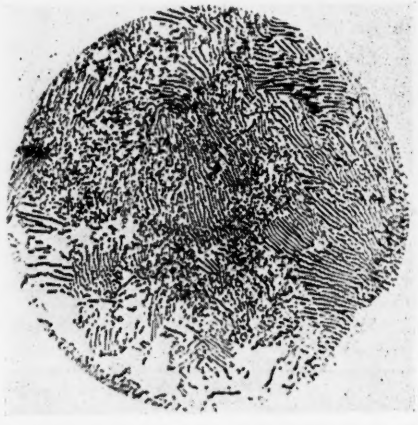

Fig. 5—Micrograph of steel N.38 transformed isothermally at 619° C, showing lamellar and non-lamellar pearlite × 800

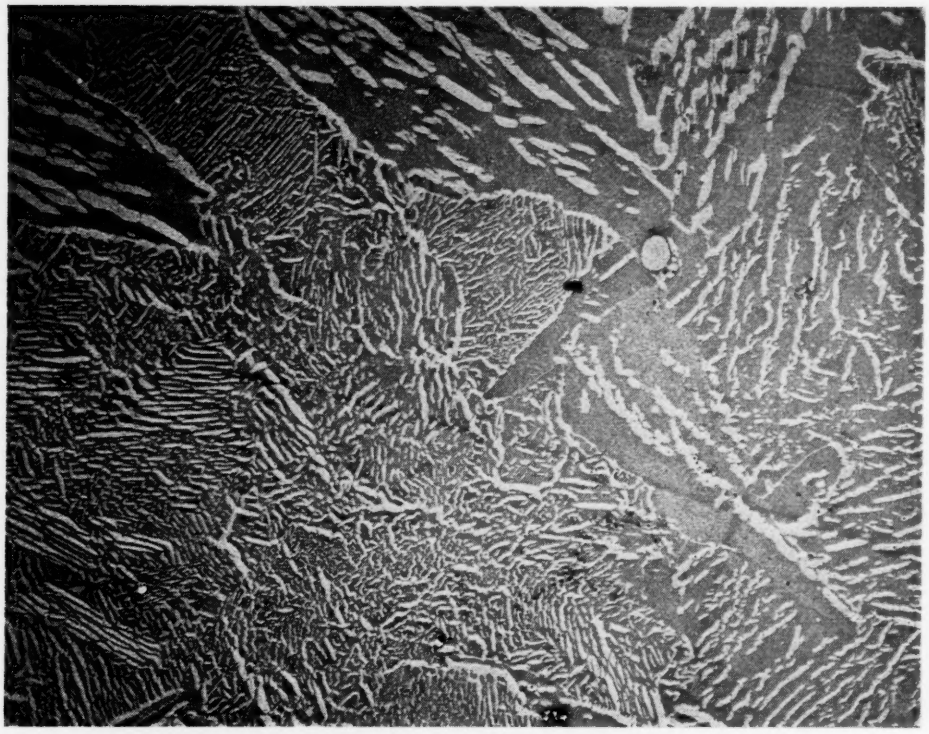

Fig. 6—Electron micrograph of steel N.38 transformed isothermally at 500° C × 7000

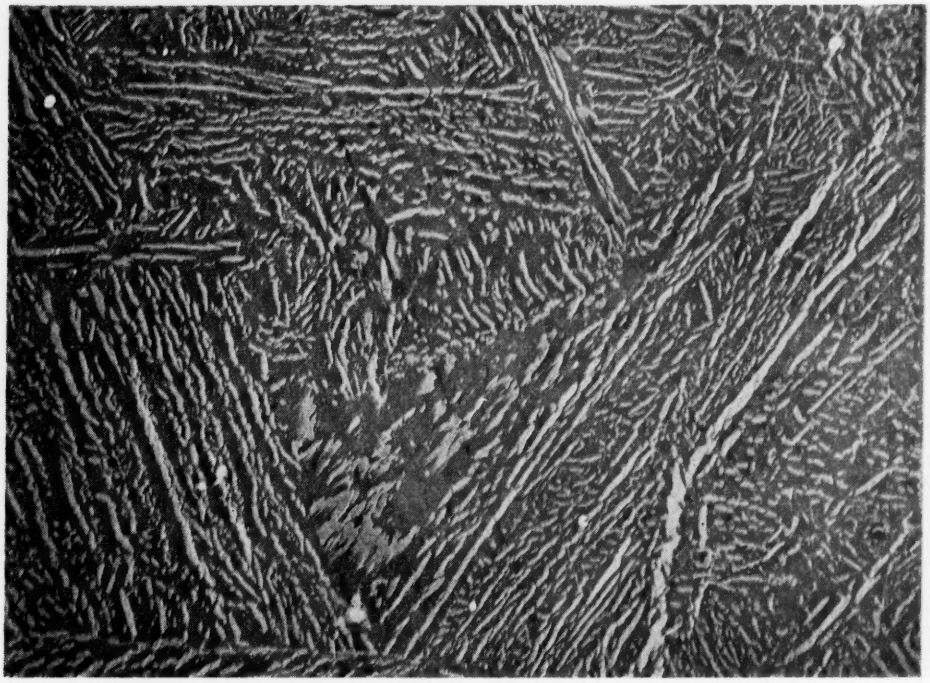

Fig. 7—Electron micrograph of steel N.38 transformed isothermally at 455° C × 7000

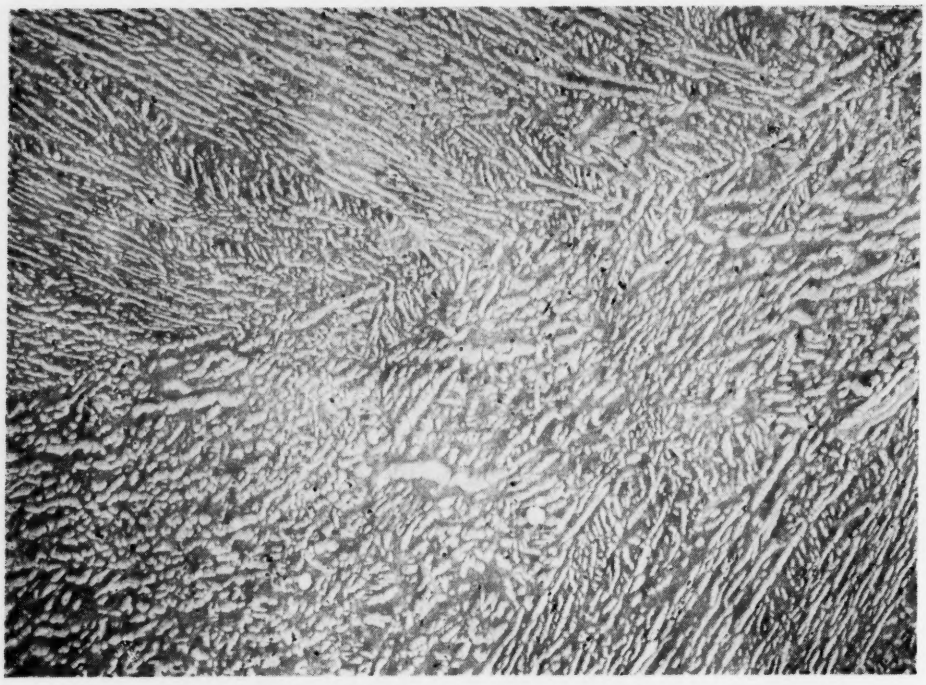

Fig. 8—Electron micrograph of steel N.38 transformed isothermally at 404° C × 7000

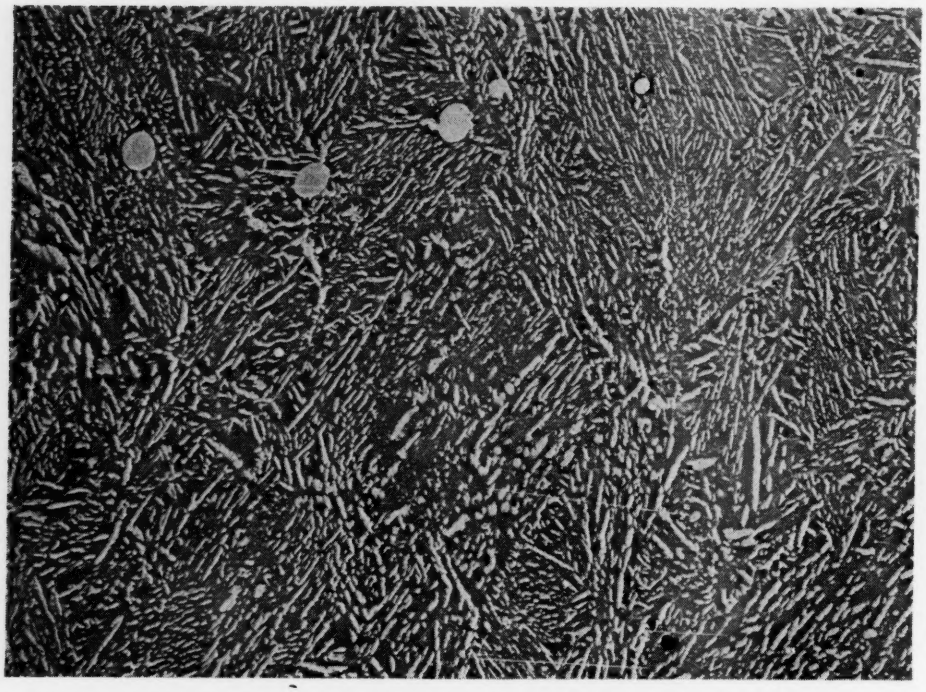

Fig. 9—Electron micrograph of steel N.38 transformed isothermally at 325° C × 7000

Fig. 10—Electron micrograph of steel N.38 partially transformed at 500° C × 7000

bainitic structures. As the structures obtained by transformation below 500° C were, in general, too fine to be resolved by the optical microscope they were studied by electron microscopy. Negative replicas, prepared by a dry-stripping technique using a solution of Formvar in dioxan, were used.

Figure 6 shows the structure of steel N.38 transformed at 500° C. Both pearlite and bainite are present, the pearlite having very much the finer dispersion of carbide. Figures 7–9 show bainites produced at successively lower temperatures. These electron micrographs show that bainite formed in 3% Ni steels consists essentially of an acicular aggregate of carbide platelets in a ferrite matrix. The carbide platelets are, in general, rather long and are oriented with their long dimension parallel to the axis of the bainite needle. With decreasing temperature of transformation the aggregate becomes progressively finer and the carbide platelets become smaller and more randomly distributed.

The structure of a specimen of steel N.38 partially transformed at 500° C is shown in Fig. 10. Here coarse bainite, fine pearlite, martensite, and retained austenite may be seen. Unfortunately several strain lines were present in the replica; these can be seen as the wavy white streaks which mainly traverse the martensite area around the middle of the micrograph. From the appearance of this micrograph it seems that bainite formation proceeds initially by the growth of ferrite needles, these needles growing most rapidly in the direction of their length. At a few places carbide precipitation is occurring at the ferrite/austenite interface, the carbide showing the characteristic platelike form with long dimension approximately parallel to the axis of the ferrite needle. For a ferrite needle to grow into the austenite it is necessary that the strain energy caused by the density change should be reduced by lowering the amount of dissolved carbon in the supersaturated ferrite. This removal of carbide can take place by diffusion into the surrounding austenite, by precipitation of carbide, or by a combination of both mechanisms. At a temperature of 500° C the rate of diffusion of carbon in austenite is still appreciable so that carbon enrichment of the surrounding austenite can occur. This might account for the relatively large amount of retained austenite (showing as an angular relief constituent within the pools of martensite) which is present in Fig. 10. The carbon content of the ferrite needles is also lowered by the precipitation of carbide at the ferrite/austenite interface.

These observations, together with the presence of pearlite in the microstructure, agree very well with the theory of bainite formation proposed by Ko and Cottrell.[5]

HEAT TREATMENT AND TESTING

Heat Treatment

The rough-machined tensometer specimens of 0·190-in. dia. were all heat treated according to the following scheme:

(i) Austenitized in salt at 875° C for 30 min
(ii) Quenched into lead at 675° C and soaked for 10 min
(iii) Quenched into lead for isothermal transformation.

Table II
CALCULATED STANDARD ERRORS OF SLOPES

Steel	Slope of Regression Line	Standard Error of Slope
N.38	− 1·0197	0·0462
N.36	− 1·0918	0·1076

For each temperature studied, four specimens were treated together. On completion of the transformation three specimens were cooled in air for subsequent tensile testing, whilst the fourth was water-quenched. This last specimen was sectioned and mounted for metallographic examination and hardness testing. Examination of the W.Q. specimen provided a check on the completion of transformation.

Tensile Testing Technique

The polished specimens were tested on a standard Hounsfield tensometer using the 2-ton beam. The accuracy of the machine was checked using a calibrated proving ring. The load recorded on the chart proved to be correct for loads greater than 0·25 ton. No loads of less than 0·25 ton needed to be included in the results so that it was possible to read the loads from the charts using a low-power microscope.

After the specimen had passed the yield point, a relaxation period of two minutes was allowed between successive strain increments. After such a period the stress relaxation which invariably occurs with intermittent straining was virtually complete for all specimens in all stress ranges. At the end of each 2-min period the smallest diameter of the specimen was measured to the nearest 0·0001 in. using a vernier micrometer and the corresponding load was recorded on the chart.

Stress/Strain Curves

Values of true stress σ and logarithmic strain q were calculated from

$$\sigma = \frac{P}{A} \quad \text{.....(1)}$$

$$q = \ln\frac{A_0}{A} = 2\ln\frac{d_0}{d} \quad \text{.....(2)}$$

where P = load, A = cross section supporting the load, A_o = original cross section, d = diameter corresponding to A, and d_0 = original diameter.

The theory and application of stress/strain curves using these variables has been widely discussed in the past decade (e.g. *see* Freudenthal[6] and Nadai[7]). Consequently we shall only consider the matter here so far as is necessary to define terms used later.

Strain may also be defined as

$$\epsilon = \ln\frac{l}{l_o} \quad \text{.....(3)}$$

and, provided that the volume of the specimen remains constant during plastic flow (this is sufficiently near to the truth for most purposes), then

$$\epsilon = q \quad \text{.....(4)}$$

A great merit of logarithmic strain values is their additive nature. This makes it easy to separate the uniform strain from the local necking strain which occurs in the later stages of testing. Such a separation is not possible using the conventional strain and reduction in area.

The strain at the maximum load, or maximum uniform strain is

$$\epsilon_u = q_u = \ln\frac{A_o}{A_u} \quad \text{.....(5)}$$

where A_u is the cross-section at the maximum load. Similarly the local necking strain is

$$\epsilon_N = q_N = \ln\frac{A_u}{A_f} \quad \text{.....(6)}$$

where A_f is the cross-section at fracture.

From equations (5) and (6) we see that

$$\epsilon_u + \epsilon_N = \ln\frac{A_o}{A_u} + \ln\frac{A_u}{A_f} = \ln\frac{A_o}{A_f} = \epsilon_f \quad \text{...(7)}$$

where ϵ_f is the total or 'fracture' strain.

RESULTS FOR PEARLITIC STEELS

Interlamellar Spacing Determination

The interlamellar spacing of the pearlite was measured by using the 'Limit Method' devised by Pearsall.[2, 3] If the fraction of the specimen that is unresolved by an objective of known resolving power is estimated, the mean interlamellar spacing, S_0 is given by

$$S_o = S\sqrt{1 - f^2} \quad \text{.....(8)}$$

where f is the fraction of the specimen unresolved and S is the spacing just resolved by the objective.

The value of S is assumed to be that predicted by Abbe's formula for resolution, i.e.

$$S = \frac{\lambda}{2(N.A.)}$$

where $N.A.$ is the numerical aperture of the objective and λ is the wavelength of the light used for illuminating the specimen.

For each specimen, 10 randomly selected fields were photographed directly on half-plate bromide paper using unfiltered light from a mercury discharge lamp. Bromide paper was selected as the recording medium because of its limited colour sensitivity and its low cost. A wedge spectrogram of the bromide paper

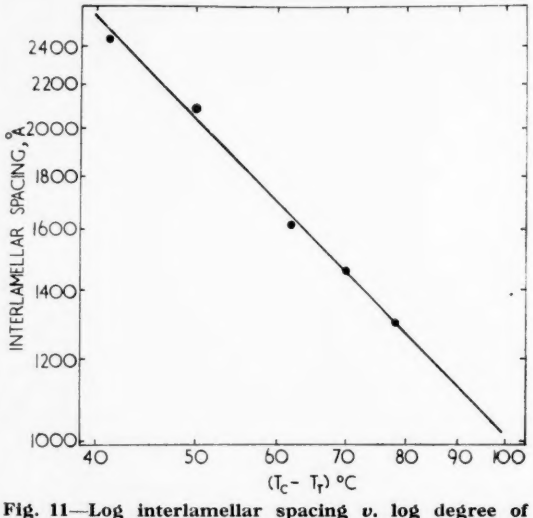

Fig. 11—Log interlamellar spacing *v.* log degree of undercooling, steel N.38, isothermally transformed

and an intensity/wavelength curve for the discharge lamp were obtained from the respective manufacturers. From these, the mean effective wavelength of the light recorded by the bromide paper was calculated and used in the Abbe formula. The numerical apertures of the objectives used had been previously determined using an Abbe apertometer. The estimation of the fraction of unresolved pearlite was done by point counting.

Although this method of determining interlamellar spacing is subject to errors, Pellissier *et al.*[3] have shown that it is probably no more inaccurate than the direct method of measuring the average distance between lamellæ on a highly magnified image.

For each specimen, the value of the mean interlamellar spacing was calculated from the individual results obtained on each of ten fields. The standard error of the mean was calculated at the same time.

Zener[8] and Fisher[9] have shown theoretically that the interlamellar spacing, S_0, should be proportional to the reciprocal of the degree of undercooling, $(T_e - T)$, where T_e is the eutectoid temperature and T is the transformation temperature If, therefore, $\log S_0$ is plotted against $\log (T_e - T)$, a straight line having a slope of -1 should result.

The results obtained for steels N.38 and N.36 are shown in Figs. 11 and 12. The straight lines drawn are those calculated by the method of least squares, each result being weighted in accordance with its standard error. The standard errors of the slopes were derived in the course of the calculations and are given in Table II.

In both cases the difference between the calculated slope and the theoretical value ($-1{\cdot}0000$) is less than the standard error of the slope. Consequently it may be stated with confidence that the results are in full agreement with the theories of Zener and Fisher. This conclusion is of considerable importance to this research because it means that the accurately known values of the degree of undercooling, $(T_e - T)$, can

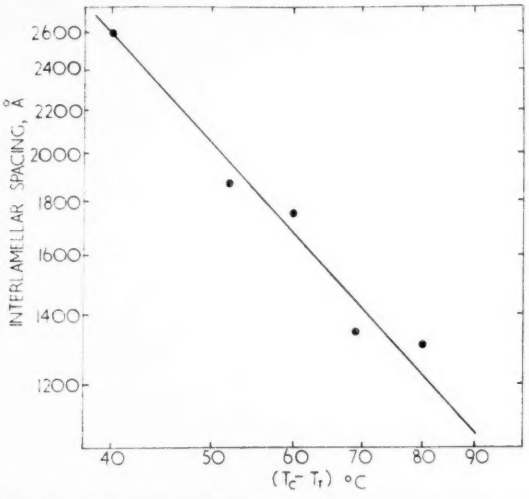

Fig. 12—Log interlamellar spacing *v.* log degree of undercooling, steel N.36, isothermally transformed

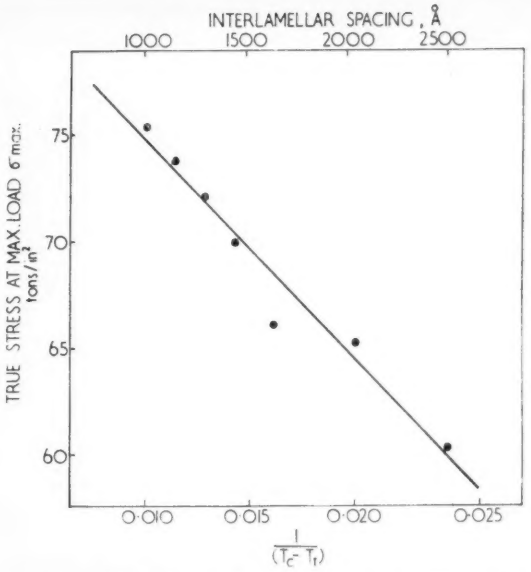

Fig. 13—Stress at the maximum load *v.* reciprocal of degree of undercooling or the calculated interlamellar spacing for steel N.38

be used instead of the less accurately known experimental values of the interlamellar spacing, S_0, when attempting to explain quantitatively the influence of microstructure on tensile test results.

The greater scatter of points in Fig. 12 as compared with Fig. 11 and the resultant greater standard error of the slope for steel N.36 is to be expected because there is a smaller proportion of pearlite in its microstructure. The estimate of the proportion of unresolved pearlite is therefore necessarily less accurate.

Strength Properties

The low-carbon steel N.34 was the only one to show distinct upper and lower yield points, although yielding was fairly pronounced and readily detectable in the other two steels. As all specimens of steel N.34 contained considerable amounts of pro-eutectoid ferrite, the influence of pearlite spacing on the strength properties is most readily deduced from the results on the other two steels.

In searching for an empirical relationship between strength properties and pearlite spacing, the simplest approach is to plot the various measured properties against various simple functions of the interlamellar spacing until a linear plot is obtained. For the reasons given earlier it is preferable to use as independent variable a function of the degree of undercooling. The simplest possibility is that the properties are linearly related to the interlamellar spacing, which was tried by plotting the various properties against the reciprocal of the degree of undercooling. It was found that a reasonably linear plot was obtained for all the strength properties. Figures 13 and 14 show typical examples; on these two graphs a calculated interlamellar spacing scale is shown but the points are plotted as functions of the degree of undercooling.

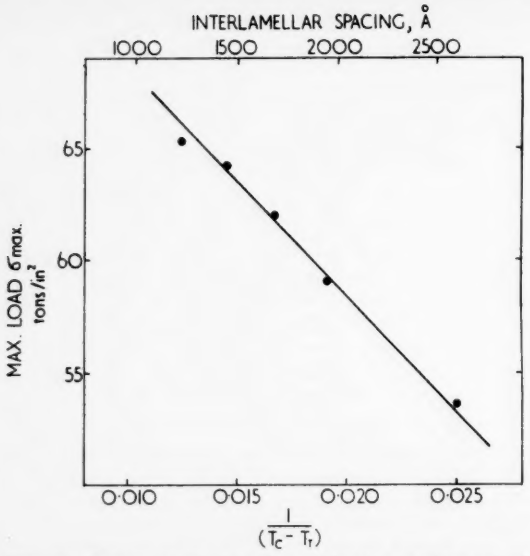

Fig. 14—Stress at the maximum load *v.* reciprocal of degree of undercooling or calculated interlamellar spacing for steel N.36

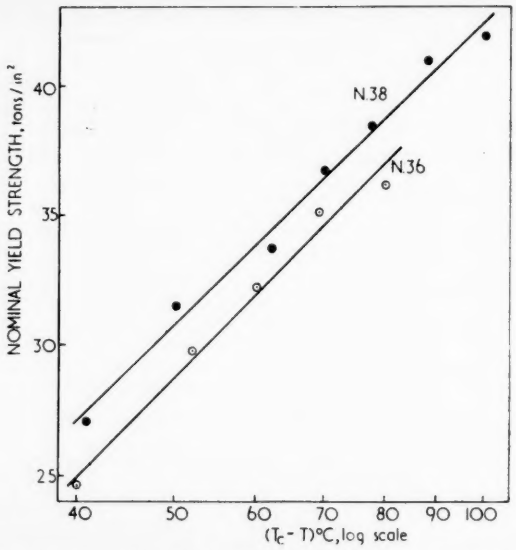

Fig. 15—Nominal yield stress *v.* log degree of undercooling for steels N.38 and N.36

Gensamer and his co-workers[1, 2] have plotted the stress at some particular strain against the logarithm of the mean free path in ferrite, the latter quantity being taken as 1·9 times the measured interlamellar spacing for pearlitic steels. On the basis of his results he has proposed the general relationship:

"*The resistance to deformation of a metallic aggregate consisting of a hard phase dispersed in a softer one is proportional to the logarithm of the mean straight path through the continuous phase.*"

This relationship was tried by plotting the various measured properties against the logarithm of the degree of undercooling. Typical results are shown in Figs. 15 and 16. Again reasonable linearity is shown, although in most cases the results for the lower-carbon steel (N.36) could be better represented by curves. That this curvature could well be associated with the presence of pro-eutectoid ferrite is confirmed by the results for steel N.34, an example of which is shown in Fig. 17.

An attempt was made to find out which of the two relationships considered so far best fits the results. Straight lines were fitted to the results by the method of least squares and a regression analysis performed in each case. These analyses indicated that the direct relationship between strength properties and pearlite spacing was slightly the better although the difference was not statistically significant. However, as the superiority of the simpler relationship was most marked in the case of the lower carbon steel (N.36) it seemed desirable to investigate the effect of making an allowance for the presence of pro-eutectoid ferrite.

An expression of the form

$$Z = a + b \log (T_c - T) + cF \quad \ldots\ldots\ldots (9)$$

where Z is a strength property, F is the percentage of ferrite, and a, b, and c are constants, was tried. Regression analysis showed that such an expression fitted the results better than the simpler direct relationship between properties and pearlite spacing. The present results would therefore seem to provide some confirmation of Gensamer's suggested relationship.

However, although Gensamer[2] has endeavoured to justify the semi-logarithmic expression in terms of dislocation theory, the relationship is best regarded as purely empirical. Gensamer's explanation appears to depend essentially on the assumption that the rate of generation of dislocations is proportional to the strain rate, yet there is no theoretical justification for such an assumption.

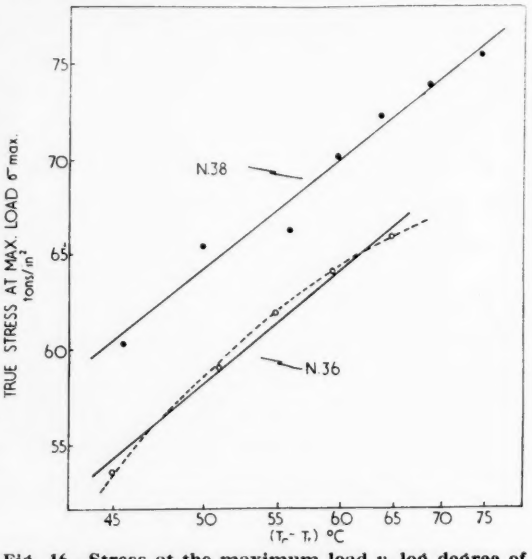

Fig. 16—Stress at the maximum load *v.* log degree of undercooling for steels N.38 and N.36

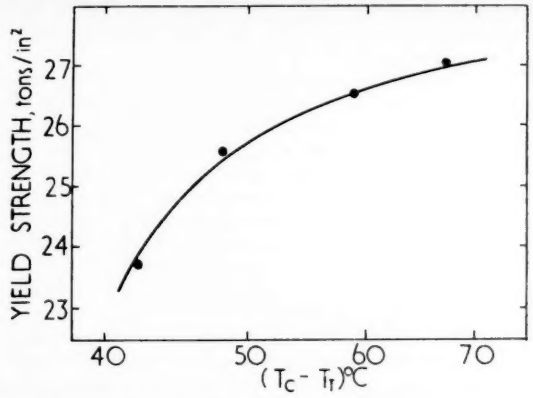

Fig. 17—Nominal yield stress *v.* log degree of undercooling for steel N.34

Eshelby, Frank, and Nabarro[10] have shown theoretically that the applied stress σ is inversely proportional to the square root of the length L of a slip band, i.e.

$$\sigma \propto \frac{1}{L^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Other workers[11, 12] identified L with the mean grain diameter in mild steel and confirmed experimentally that the yield point varies linearly with the reciprocal of the square root of the grain diameter. In a pearlitic material it seems reasonable to identify L with the mean dislocation path along which slip can occur in pearlite. We may suppose this distance to be the average distance between successive cementite lamellæ measured in all possible directions. This ' mean free path ' will be the product of the measured interlamellar spacing and some constant

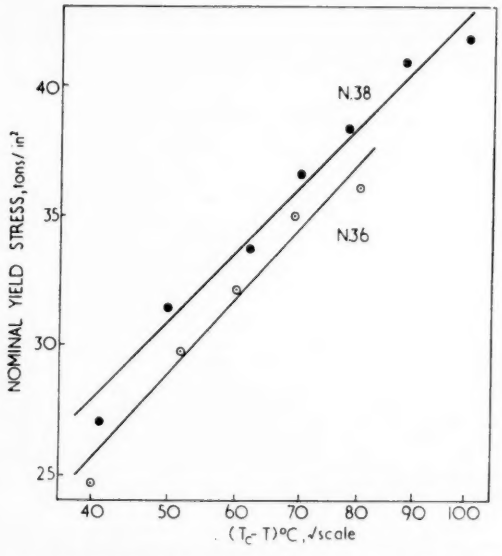

Fig. 18—Nominal yield stress *v.* square root of degree of undercooling for steels N.38 and N.36

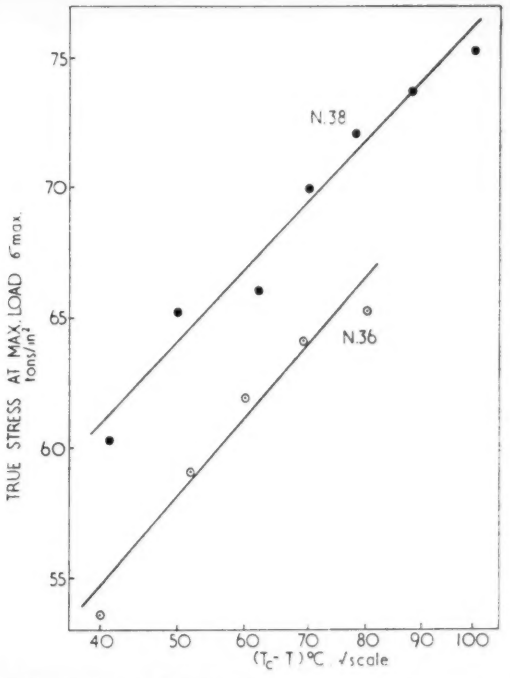

Fig. 19—Stress at the maximum load *v.* square root of degree of undercooling for steels N.38 and N.36

greater than unity. Hence we may expect relationships of the form

$$Z = a + \frac{b}{S_0^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Accordingly, strength properties were plotted against $(T_e - T)^{\frac{1}{2}}$, the degree of undercooling being preferred as independent variable. The linearity of the plots was good (e.g. *see* Figs. 18 and 19). Again a regression analysis was performed in each case to ascertain the goodness of fit. The expression proved to be not quite as satisfactory as the semi-logarithmic relationship. However, on introducing a term allowing for the amount of ferrite, i.e. using equations of the type

$$Z = a + \frac{b}{S_0^{\frac{1}{2}}} + cF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

the fit is very considerably improved and becomes practically the same as for the semi-logarithmic equations of type (9). It is quite impossible to assess the relative merits of the two types of expression statistically with the present results. Both types of equation fit very well and the differences between them are totally insignificant. However, it may be of interest to note that the inclusion of a ferrite term has a greater effect on the $(T_e - T)^{\frac{1}{2}}$ expression than on the log $(T_e - T)$ type; this may imply that the former may better represent the effect of interlamellar spacing alone.

Ductility

The ductility results for the three steels are shown in Figs. 20–22. All three steels show a maximum in the necking strain and the total strain, which occurs

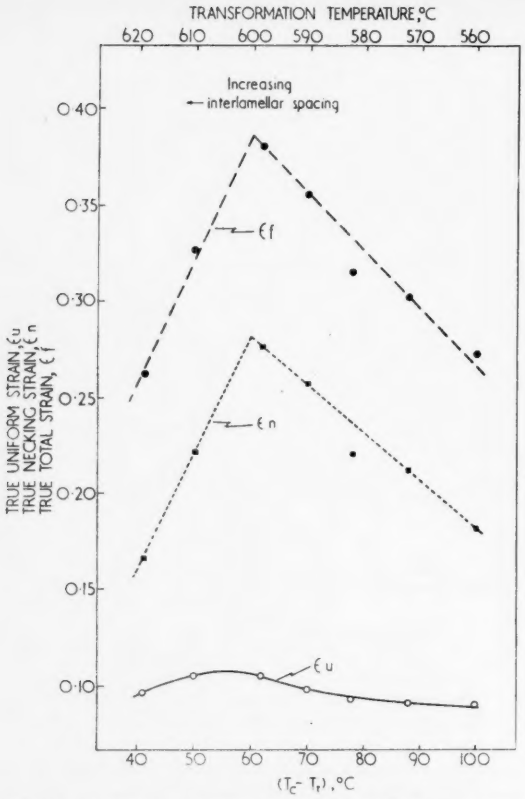

Fig. 20—Strains *v.* degree of undercooling or transformation temperature for steel N.38 transformed isothermally to pearlite

at 610° C for steel N.34 and at 600° C for the other two steels. As the necking strain is in all cases very much greater than the uniform strain, the total strain results are merely a reflection of those for necking strain. It is surprising that the capacity of these steels for local deformation decreases as the transformation temperature rises above about 600° C, and no explanation can be offered. The phenomenon is not peculiar to these steels as examination of Gensamer's results[2] reveals the same effect. For the two lower-carbon steels the uniform strain decreases steadily with decreasing transformation temperature. In the case of the 0·67% C steel (N.38) the uniform strain shows a maximum at about 600° C. It is thought that this may be associated with the presence of a little free cementite in specimens of this steel transformed at temperatures above 600° C.

RESULTS FOR THE 0·67% C STEEL IN THE BAINITIC CONDITION

Strength Properties

Specimens of the 0·67% C steel (N.38) transformed isothermally at selected temperatures in the range 500–400° C were tested on the Hounsfield tensometer. Specimens transformed at 350° C were too strong for this machine and were tested on an Amsler hydraulic machine of 5 tons capacity. For these tests straining was continuous at a rate of about 0·0003 per second.

The Nominal Yield Strength and the Stress at Maximum Load were plotted against the degree of undercooling (or transformation temperature). Both curves were similar, as is shown in Figs. 23 and 24 in which the results for the steel in the pearlitic condition are included for comparison. The authors have made no attempt to find a function of the transformation temperature against which the strength properties would plot as a straight line. It might be thought that some such function as log $(T_B - T)$, where T_B is the ' bainite start ' temperature, might be suitable. It is, however, obvious that no such logarithmic function can linearize a plot which is concave upwards. The same reasoning precludes the use of any of the other functions considered in the section on pearlitic steels. There is no theoretical guidance to the choice of a more complex function and the authors consider that the search for an empirical relationship would not be worth while.

Figure 23 reveals that specimens transformed at the lower temperatures in the pearlite range have higher necking stresses than those transformed in the higher temperature range of bainite formation.

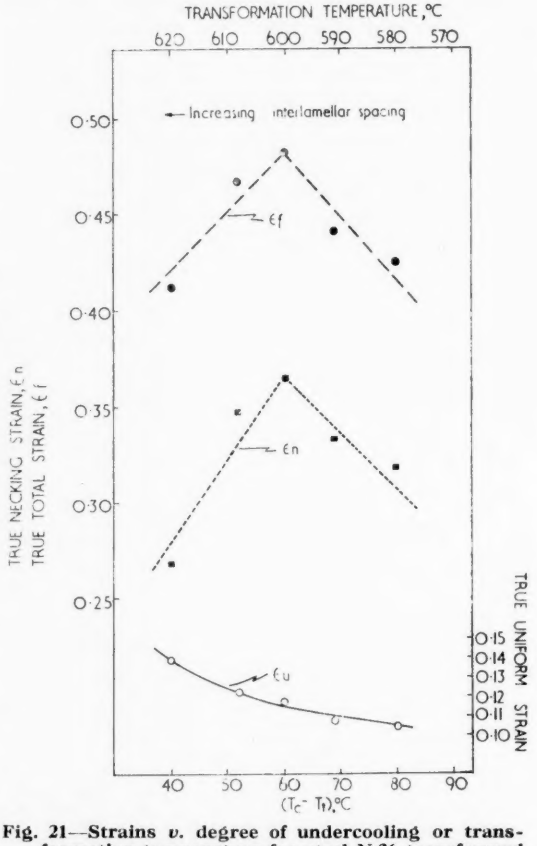

Fig. 21—Strains *v.* degree of undercooling or transformation temperature for steel N.36 transformed isothermally to pearlite.

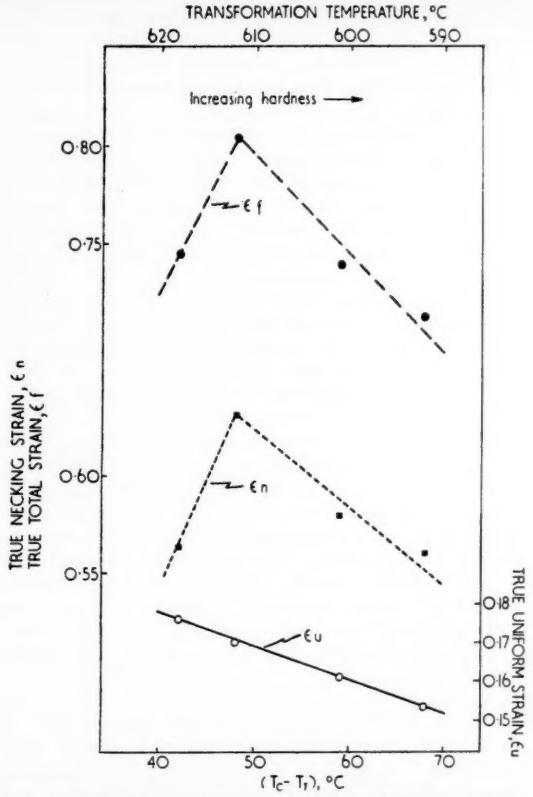

Fig. 22—Strains *v.* degree of undercooling or transformation temperature for steel N.34 transformed isothermally to pearlite

It is found, for example, that the specimen transformed to pearlite at 560° C is stronger than one transformed to bainite at 475° C, although the bainitic specimen has the greater Vickers hardness (328 and 315) for the bainitic and pearlitic specimens respectively).

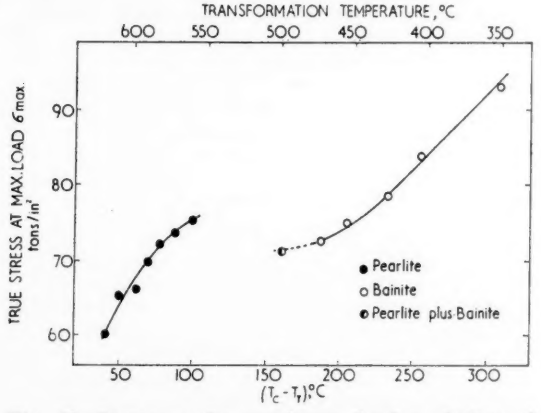

Fig. 23—Stress at the maximum load *v.* degree of undercooling or transformation temperature for steel N.38 transformed isothermally to bainite and pearlite

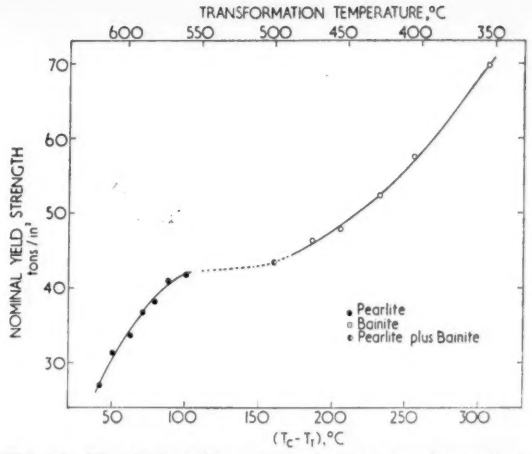

Fig. 24—Nominal yield stress *v.* degree of undercooling or transformation temperature for steel N.38 transformed isothermally to bainite and pearlite

It has been generally accepted that there is a simple relationship between the hardness of a metal and its U.T.S. This relationship may be written

$$T_u = cH \quad \text{.....(13)}$$

where T_u is the U.T.S. and H is the hardness number (Brinell or Vickers).

Tabor[13, 14] has shown that the value of the constant c depends on the Meyer index of the material. It seems reasonable to expect a similar relationship to apply to the necking stress σ_{max} and the results obtained for specimens of steel N.38 in both pearlitic and bainitic conditions are plotted in Fig. 25.

It is apparent that straight lines may be drawn through each set of points but that the lines have similar slopes. If a simple relationship of the type

$$\sigma_{max} = bH \quad \text{.....(14)}$$

applies, then the slopes of the lines should be different.

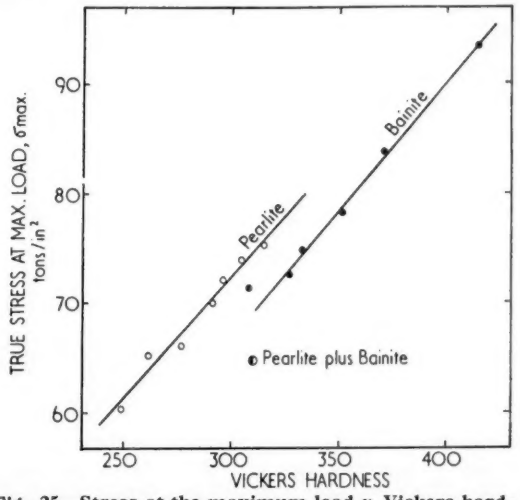

Fig. 25—Stress at the maximum load *v.* Vickers hardness for steel N.38 in pearlitic and bainitic conditions

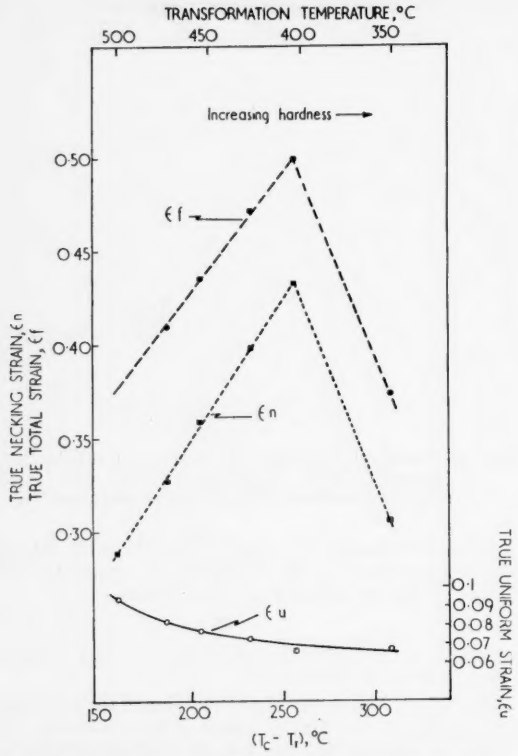

Fig. 26—Strains *v.* degree of undercooling or transformation temperature for steel N.38 transformed isothermally to bainite

To check whether the slopes are in fact the same, an equation of the type

$$\sigma_{max} = a + bH \quad \text{.....(15)}$$

was fitted by least squares to each set of results. The calculated values of b (i.e. the slopes) are 0·22 and 0·23 for pearlite and bainite respectively. The difference between these figures is not significant when the scatter of the results is taken into account. The values of the intercept parameter a are considerably and significantly different, being 5·98 for the pearlitic specimens and — 3·58 for the bainitic specimens. A general relationship between strength and hardness should not contain an intercept parameter since the two variables would be expected to be zero simultaneously. However, equation (15) fits the results much better than equation (14) and would appear to be a satisfactory empirical relationship for two-phase structures. Specimens of the same steel in the quenched and tempered condition also give results which may be best represented by equation (15), and again the proportionality constant is about 0·23.

Ductility Results

As shown in Fig. 26, the uniform strain for steel N.38 in the bainitic condition decreases gradually with decreasing transformation temperature. The local necking strain shows a maximum for a transformation temperature of about 400° C. Since the necking strain accounts for by far the greater proportion of the total strain, the latter plots in a similar way to the former. A plot of the conventional reduction in area would be similar to that shown for total strain.

Comparison of Figs. 26 and 20 shows that the ratio of necking strain to uniform strain is much higher for bainitic specimens of steel N.38 than for pearlitic specimens. Also, the general level of the necking strains is considerably higher for bainitic specimens in spite of their greater hardness and strength. This may well be a general phenomenon not restricted to this particular steel, since Hollomon and others[15, 16] have shown that steels having bainitic microstructure exhibit better notched-impact properties than do the same steels with pearlitic microstructures, and good impact properties are usually associated with a large capacity for localized deformation.

The increase in local strain as the hardness of the material increases up to a maximum for specimens transformed at about 400° C is surprising. The same phenomenon is shown in the reduction in area/transformation-temperature curves published by Gensamer,[2] so it would appear to be a general characteristic of bainitic steels. This behaviour is similar to that shown by the pearlitic steels and it may be that the effect is associated with the average distance apart of cementite particles in the two types of structure. It has been pointed out earlier that bainite formed at 500° C is much coarser than pearlite formed at the same temperature. However, bainite formed at 400° C is considerably finer than pearlite formed at 600° C, so that the maxima shown in Figs. 20 and 26 do not relate to the same degree of fineness of structure.

Several workers[17–20] have shown that under some circumstances small amounts of austenite may be retained in steels transformed in the bainite range. Such austenite, which is not readily detectable metallographically, might influence the ductility of bainitic steels because it undergoes stress-induced transformation to martensite.[21–24] Specimens of steel N.38 in the bainitic condition were investigated by an X-ray diffraction technique similar to that described by Cameron[20] and others.[25, 26] The sensitivity of the method is not great, but 3% or more of austenite could be detected. In no case did the experiments give a positive result so it seems reasonable to suppose that the bainitic specimens are fully transformed and that the ductility figures are not influenced by retained austenite.

DISCUSSION

It has been shown that satisfactory isothermal transformation of small tensile test-pieces having a smallest diameter of the order of 0·2 in. could not be achieved with plain carbon steels. Some alloying addition was required and nickel was selected because it does not form complex carbides. An addition of 3% Ni was found to be the minimum for satisfactory results, even though a smaller test piece was used.

The relationship between the transformation temperature and the interlamellar spacing of pearlite was investigated and it was found that the spacing is

inversely proportional to the degree of undercooling, thus supporting the theories of eutectoid decomposition proposed by Zener[8] and Fisher.[9] The confirmation of this relationship was of considerable value because it permitted the use of the accurately known degree of undercooling instead of the measured interlamellar spacing when relating tensile properties to microstructure.

The main strength properties selected for correlation with microstructure were the nominal yield stress (i.e. the stress required to initiate plastic deformation), the stress at maximum load (i.e. the highest stress the test piece will sustain under conditions of uniform deformation), and the hardness. It was found that all these quantities could be related by linear equations to the interlamellar spacing, to the logarithm of the interlamellar spacing, or to the reciprocal of the square root of the spacing. The last two relationships were the most satisfactory provided that allowance was made for the effects of varying amounts of pro-eutectoid ferrite. The logarithmic expression has been suggested previously by Gensamer[2] but it has been pointed out that the theoretical justification of this relationship is faulty. The relationship between the strength properties and the reciprocal of the square root of the interlamellar spacing seems justified from the theoretical work of Eshelby, Frank, and Nabarro.[10]

The strength properties of specimens of the 0·67% C, 3·0% Ni steel (N.38) transformed isothermally in the bainite range have been determined. The rapid increase in the strength of the bainitic steel with decreasing transformation temperature may be taken as evidence that the average slip distance in the bainite decreases as the transformation temperature is lowered. This is in accordance with the electron micrographical observations which show that the structure of the bainite becomes progressively finer as the transformation temperature falls. The average slip distance in bainite is, however, a function not only of the general fineness of the structure but also of factors such as the shape of the cementite particles and the relative orientation of the cementite and the ferrite.

The ductility results for the steels in both pearlitic and bainitic conditions showed unexpected maxima when the necking strain and fracture strain were plotted against degree of undercooling or transformation temperature. No satisfactory explanation of these results can be offered.

Comparing the ductility results for the 0·67% C steel (N.38) in the pearlitic and bainitic conditions, it is noticed that in general the bainitic specimens, though appreciably stronger than the pearlitic specimens, show greater local strains and total strains. The greater total ductility of the harder bainitic steels is not difficult to understand. During the progress of deformation, dislocations will pile up against cementite particles at the points where the slip planes in ferrite meet the cementite. At these points, regions of very high localized stress will build up, and when the stress concentrations become great enough cracks will form in the cementite. Bruckner[27] and Lorig[28] have reported that the process of fracture in pearlitic steels began in one or more of the carbide lamellæ. Zednik and Kaderavek[29] testing a pearlitic eutectoid plain carbon steel (by the notched-bar impact test) found that microcracks arise selectively at the ferrite/cementite interface and that these cracks extend across the grains in directions other than parallel to the lamellæ.

The effectiveness of a cementite particle in blocking slip and establishing stress concentrations will depend largely on its surface area and therefore on its shape. The cementite in pearlite exists essentially as thin plates which will be very effective in blocking slip. The cementite particles in bainite, whilst plate-like in shape, are much thicker in proportion to their other dimensions than are those in pearlite. The bainitic cementite may be expected to be less effective in setting up stress concentrations and will also require higher values of local stress to initiate fracture in the relatively thicker particles. Consequently a bainitic material will have a higher fracture stress than a pearlitic one and this will be reflected in higher local necking strains.

CONCLUSIONS

(1) Tensometer specimens of a plain carbon eutectoid steel cannot be transformed isothermally at the lower temperatures in the pearlite range.

(2) Tensometer specimens of a nearly eutectoid (0·67% C, 3% Ni) steel transform under strictly isothermal conditions at all temperatures in the pearlite and bainite ranges.

(3) Tensometer specimens of lower-carbon, 3% Ni steels transform isothermally only over limited ranges of temperature.

(4) Interlamellar spacing of pearlite formed isothermally is inversely proportional to the degree of undercooling.

(5) Strength properties of the steels in the pearlitic condition are linearly dependent on the reciprocal of the square root of the interlamellar spacing when allowance is made for the effect of pro-eutectoid ferrite.

(6) Strength properties of pearlitic steels may be related linearly to the logarithm of the interlamellar spacing, but there is no theoretical justification for such a relationship.

(7) Local necking strain and the total strain of specimens of the 0·67 and 0·55% C, 3% Ni steels transformed isothermally to pearlite are a maximum for specimens transformed at about 600° C.

(8) Strength properties of the 0·67% C, 3·0% Ni steel, transformed in the bainitic region, increase rapidly with decreasing transformation temperature but no simple functional relationship describes the results.

(9) Bainitic specimens, though appreciably harder and stronger than pearlitic specimens of the same steel, show greater capacities for localized deformation than do the latter.

Acknowledgments

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The Effect of Cold Work on the Creep-Rupture Properties of a Series of Simple 18–8 Stainless Steels

By Frank B. Cuff, Jun., and Nicholas J. Grant

SYNOPSIS

The effect of cold work on the creep-rupture properties of a series of six simple 18–8 stainless steels at 1100° and 1200° F has been investigated. Four levels of cold work (annealed to 35%) were studied. The compositional variation—15·7–21·8% Cr, 8·7–13·9% Ni, and 0·042–0·075% (C + N_2)—resulted in a M_s temperature variation from + 100° F to absolute zero.

Creep-rupture properties were compared, both for each steel at various levels of cold work and for the series of steels at equivalent levels of cold work. A relationship was found among the composition, M_s temperature, recrystallization temperature, and rupture life. Conclusions were drawn regarding the predictability of high-temperature properties as influenced by alloy content and the degree of cold work. Room-temperature properties of each steel were determined. 1338

A KNOWLEDGE of the effects of cold work on both long- and short-time creep-rupture properties of metals is necessary for the proper design of certain fabricated parts for high-temperature service. In particular, it is important to know the benefits which can be derived and the time–temperature limitations of these benefits as a result of any structural instabilities that may exist.

Only a limited number of investigations have been made of the effect of cold work on the creep-rupture properties of metals at high temperatures. Benefits have been noted in copper and aluminium alloys in the absence of rapid recovery or recrystallization. Optimum levels of cold work were found for Monel[1] and for two austenitic stainless steels.[2, 3] Similar improvements in creep-resistance were noted for N–155,[4] a high-temperature alloy, and for a Cr–Mo steel.[5] In the latter instance a minimum in creep-resistance was noted at 800° and 900° F, which was explained on the basis of the Bauschinger effect.

It was the purpose of this investigation to study the effect of cold work on the creep-rupture properties of a series of stainless steels which, by composition selection, were subject to a variety of structural and phase instabilities.

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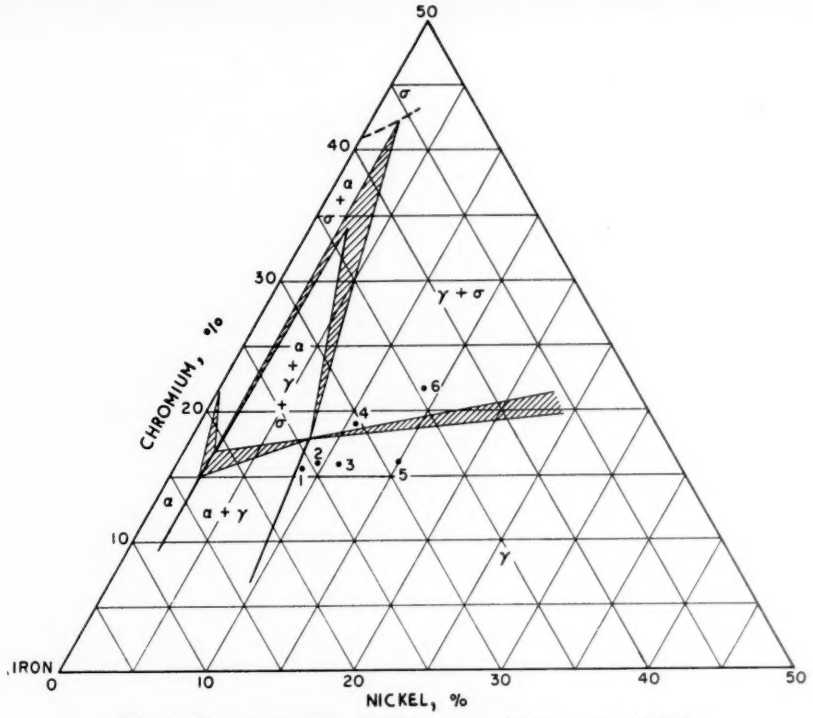


Fig. 1—Iron–chromium–nickel ternary diagram for 1200° F

MATERIALS AND EXPERIMENTAL METHODS

The steels used for this investigation are listed in Table I. All the heats were prepared in a 40-lb induction furnace and poured as 25-lb ingots at approximately 2800° F into graphite moulds. In each case the furnace charge consisted of weighed amounts of ingot iron, electrolytic nickel, and low-carbon ferrochromium, added in that order, and finally deoxidized with a Ca–Mn–Si alloy. The ingots were hot-forged to ½-in. dia. bars at a finishing temperature of 1900° F. Samples were taken from the bar stock for chemical analyses.

In order to conserve material, the various degrees of cold work were divided into four batches and were cold-swaged to different diameters, the smallest being ⅜ in. These bars were then annealed at 1850° F for 2 h and water-quenched to the fully softened condition. All but the smallest-diameter bars were then cold-swaged to ⅜ in., this operation introducing three predetermined amounts of cold work. Including the annealed bars, the levels of cold work were approximately 0, 15, 25, and 35%, based on reduction in area.

Creep-rupture specimens with a diameter of 0·250 in. and a test section 1 in. long were machined from these bars. Each of the specimens was then electropolished to improve the surface, using a technique described by Fiedler *et al.*[6]

The equipment used for the creep-rupture tests is fully described elsewhere[7] and conforms to A.S.T.M. requirements. The times-to-rupture ranged from 0·01 to 1000 h and the test temperatures were 1100° and 1200° F. Steel 3 was also tested at 1300° F.

After testing, each specimen was sectioned, mounted, mechanically polished, and etched, to reveal the type of fracture and any metallurgical changes which might have taken place. The etching technique was the same as that for electropolishing, except that a lower voltage was used.

The identification of certain precipitates that were observed after testing was accomplished by using an electrolytic separation technique described by Blickwede and Cohen.[8] The residues resulting from this separation were identified by X-irradiation.

An approximate quantitative measure of ferrite (martensite) present in some of the steels was determined by a Magnegage.

For steels with M_s temperatures above that of liquid nitrogen, the M_s temperatures were found by using a resistance method described by Monkman, Cuff, and Grant.[9]

Table I

ALLOY COMPOSITIONS (%)

Steel	Chromium	Nickel	Carbon	Nitrogen	C + N_2	M_s (° F)
1	15·73	8·73	0·028	0·030	0·058	+ 100*
2	16·16	9·43	0·036	0·032	0·068	− 125*
3	16·01	11·08	0·025	0·026	0·051	− 300*
4	19·11	10·60	0·020	0·022	0·042	− 340†
5	16·33	14·83	0·028	0·028	0·056	− 627†
6	21·76	13·93	0·035	0·040	0·075	− 936†

* Determined by electrical resistivity method[9]
† Calculated M_s values[5]

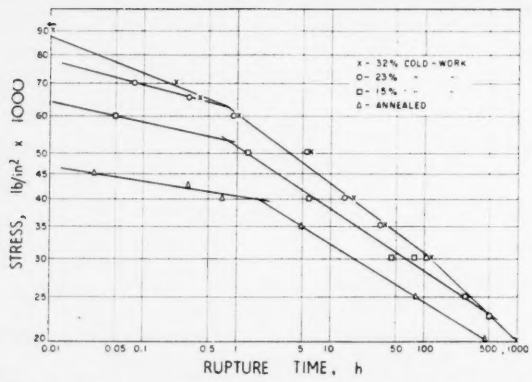


Fig. 2—Log stress/log rupture-time plots for steel 3 at 1100° F as a function of cold work

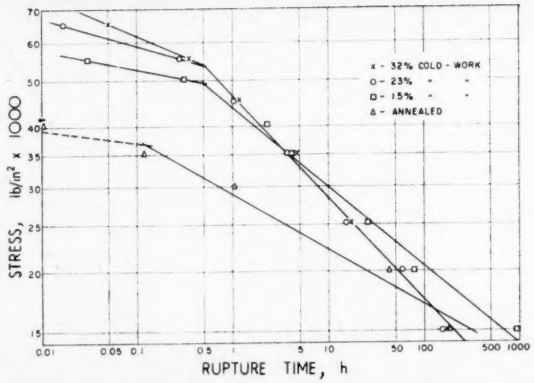


Fig. 3—Log stress/log rupture-time plots for steel 3 at 1200° F as a function of cold work

Tensile tests, as a means of comparing high- and low-temperature properties, were run on a Baldwin-Southwark tensile testing machine, using a Huggenberger strain gauge for measuring extensions.

RESULTS

It was thought advisable to refer to the ternary Fe–Cr–Ni diagram as a starting point in order to choose alloys that would best show the influence of composition and structure on the response of these alloys to cold work.

The diagram of Nicholson, Samans, and Shortsleeve,[10] shown in Fig. 1, was selected because it was felt that the techniques used gave the closest approach to equilibrium, and the levels of certain impurity elements were close to those of the steels used in this investigation. The shaded areas in Fig. 1 indicate the uncertainty in boundary determinations.

From Table I it will be seen that steels 1, 2, 3, and 5 have about 16% Cr, while the proportion of nickel increases from about 8·5% to 14·5% in the above order. Steels 4 and 6 have nickel levels corresponding approximately to those of steels 3 and 5 (11% and 14%), but at higher chromium percentages, 19% and 21·5% respectively. The six steels had 0·042–0·075% ($C + N_2$). While this appears to constitute a very small spread of values, a change from 0·042% to 0·075% can contribute significantly to the high-temperature short-time strength of such steels,[11, 13] The influence of small compositional differences is considered below. The compositional variation of these steels provides a variety of initial structures that are subject to change under creep-rupture test conditions; there are also important differences in recrystallization temperature. To establish a basis of comparison for the effects of cold work, each steel was tested not only at various levels of cold work but also in the annealed condition.

Table II shows the quantity of martensite present in each steel before testing. Where the M_s temperature was less than − 320° F, values of M_s were calculated (steels 4, 5, 6).[9] Note the decrease in martensite percentage with increasing alloy content.

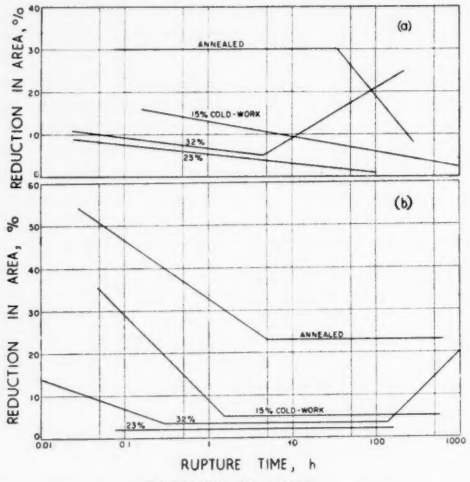
Figures 2 and 3 are typical curves showing the effect of cold work at 1100° and 1200° F on the creep-rupture properties of steel 3, a relatively unstable steel (*see also* Table II). At each temperature an optimum level of cold work for a desired rupture life is apparent. Figure 4 shows the change of reduction in area at fracture for steel 3, at each of the two temperatures, as a function of rupture life and degree of cold work. Figures 5 and 6, on the other hand, show the effect of cold work on steel 6, a relatively stable

Table II

% MARTENSITE AS A FUNCTION OF COLD WORK

Steel	Annealed	Cold work 15%	Cold work 25%	Cold work 35%	M_s Temperature, °F
1	32	60	73	85	+ 100*
2	...	12	26	40	− 125*
3	...	5	8	12	− 300*
4	...	...	...	trace	− 340†
5	...	...	...	...	− 627†
6	...	...	...	...	− 936†

* Measured by resistivity method[9]
† Calculated values[9]



(*a*) 1200° F (*b*) 1100° F

Fig. 4—Variation of reduction in area for steel 3 as a function of rupture-time

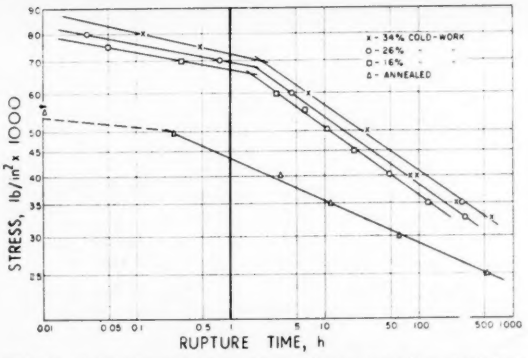


Fig. 5—Log stress/log rupture-time plots for steel 6 at 1100° F as a function of cold work

steel (*see also* Table II). In this case there is a continuing positive response to cold work up to the highest level of cold work investigated, for at least 600 h at 1100° F and up to 100 h at 1200° F. The instability region, occurring at about 100 h (Fig. 6) for the 34% cold-worked steel, is associated with sigma growth at the grain boundaries. A similar instability was found for steel 4 (*see* Fig. 15). Figure 7 shows the change of reduction in area for steel 6 as a function of rupture life and degree of cold work.

Ductility, measured as reduction in area, showed an inverse relationship to creep-rupture properties, such that low ductility was associated with good creep-rupture properties and *vice versa*.

One of the aims of this investigation was the evaluation of the relative effectiveness of cold work as a function of composition and the time-temperature-stress stability of the structure. Accordingly, curves of the types shown in Figs. 2–7 were obtained for each of the steels, using about the same number of points as a plotting convention to delineate the curves and establish any deviations from linearity in the log-log figures, to detect regions of material instability. For each level of cold work and at each temperature comparisons of log stress versus log rupture-time were

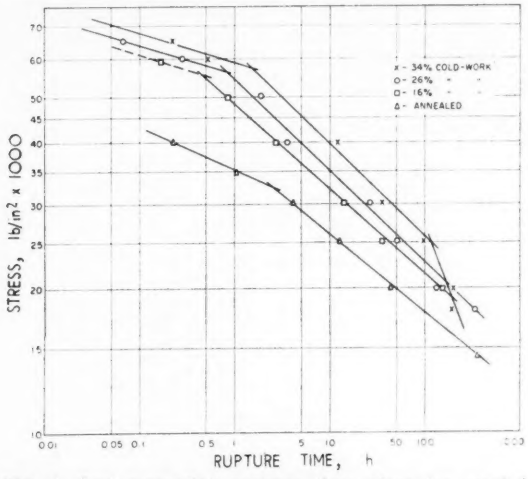
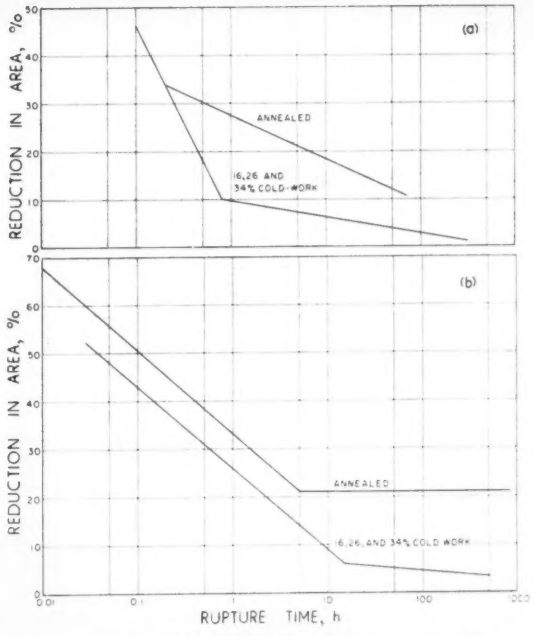


Fig. 6—Log stress/log rupture-time plots for steel 6 at 1200° F as a function of cold work



(*a*) 1200° F (*b*) 1100° F

Fig. 7—Variation of reduction in area for steel 6 as a function of rupture-time

then made and are shown in Figs. 8–15. From the individual curves for each alloy, the optimum level of cold work for 100-h rupture time was determined for each steel at each of the test temperatures. These results are summarized in Table III.

Values of yield strength (0·2% offset), tensile strength, and hardness (Rockwell *A*), prior to test, were also obtained for each steel in each condition of cold work. The variations of yield strength and hardness with cold work are shown in Figs. 16 and 17.

DISCUSSION

Creep-Rupture Results of Individual Steels

The improvement in creep resistance resulting from cold work must be explained primarily in terms of lattice strains introduced by the cold work, barring important phase changes or ageing phenomena introduced by such cold work. Conversely, the time-temperature dependent recovery of these strains during testing may be expected to result in a lessening of creep resistance. However, evidence has been presented showing that the recovery rate for this

Table III

OPTIMUM LEVELS OF COLD WORK BASED ON 100-h RUPTURE LIFE

Steel	1100° F	1200° F
1	12	...
2	12	12
3	23	15
4	34 or greater	25*
5	34 or greater	24
6	34 or greater	34*

* Sigma formation effective as a weakening influence at about 100 h

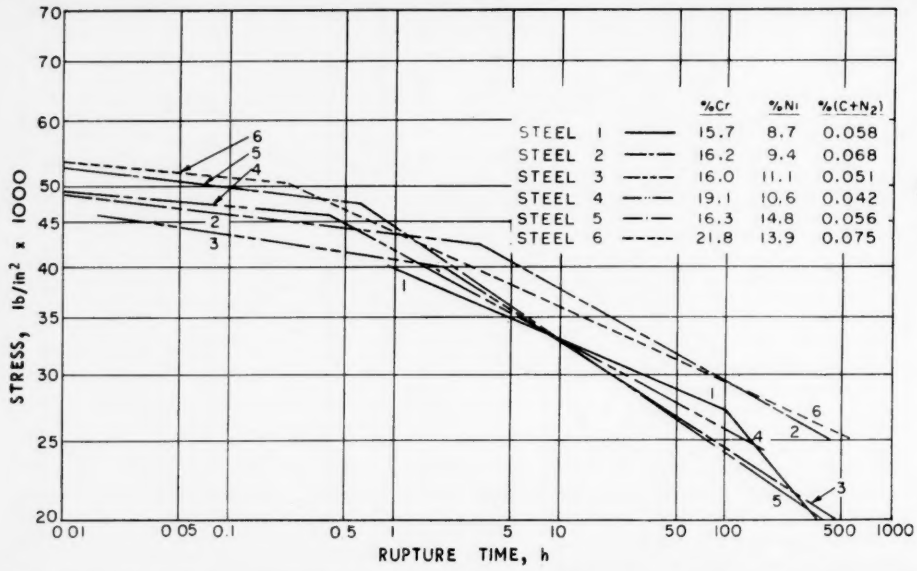


Fig. 8—Comparative creep-rupture plots of annealed steels at 1100° F

type of steel is probably relatively slow[4]; it is so slow at temperatures below 1200° F that the assumption has been made that the cold-work-induced strains are largely retained under the test conditions used in this study.

Therefore, the optimum levels of cold work shown in Table III must be explained in terms of processes that are consequences of cold work and which, upon being exceeded, promote the removal of residual strains with an accompanying deterioration in strength properties.

In this regard, the variation of strength with temperature, composition, and structure may be explained primarily on the basis of the stability and alloying of the austenite, or conversely on the presence of prior-martensite and its tempering and recrystallization. While the concurrent and interrelated phenomenon of carbide precipitation cannot be disregarded, it is felt that its effect is of importance only in the annealed structures and of secondary importance in the cold-worked steels; and that its role, while predictable, is in a large measure obscured by the effect of martensite tempering and recrystallization. Accordingly, carbide precipitation will be discussed only in a qualitative manner, its influence having been covered in a recent study of annealed stainless steels.[11]

The prior-room-temperature structures, annealed and after cold work, are partially described in Table II. It has further been shown[9] that the room-temperature

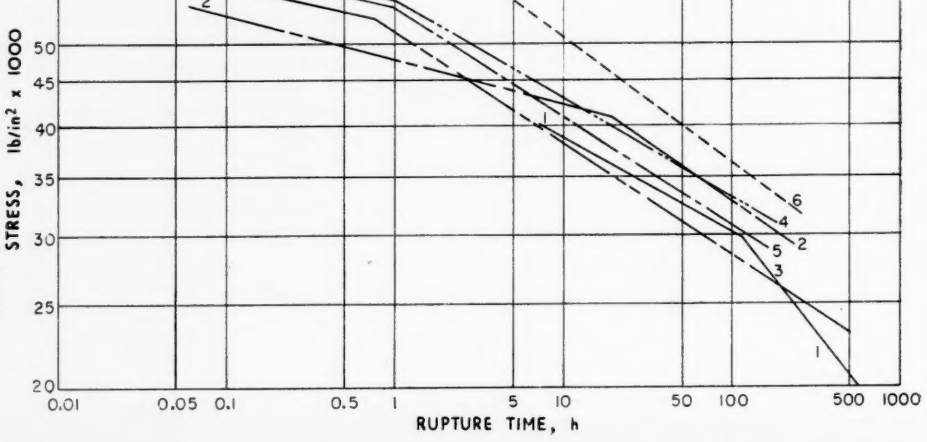


Fig. 9—Comparative creep-rupture plots of 15% cold-worked steels at 1100° F

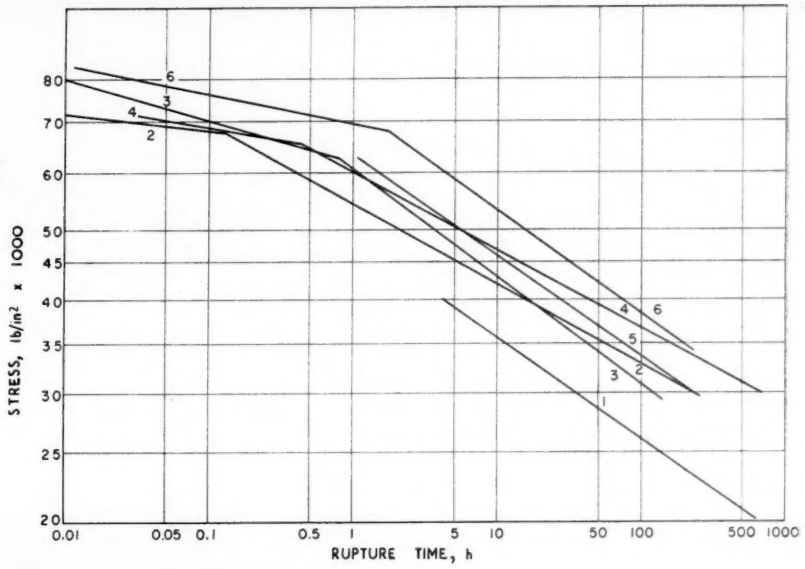


Fig. 10—Comparative creep-rupture plots of 25% cold-worked steels at 1100° F

martensite decomposes to austenite plus carbide in a relatively short time above about 1100° F for these steels.

All but steel 1 were austenitic in the annealed condition; steel 1 had an M_s temperature of + 100° F. With increasing cold work, steels 1, 2, and 3 showed increasing amounts of martensite, and steel 4 showed a trace only after 34% cold work, whereas steels 5 and 6 were free of any evidence of martensite even after 34% cold work. With increasing alloy content and cold work the initial structures encountered were (*a*) annealed austenite plus martensite, (*b*) annealed austenite, (*c*) cold-worked austenite plus martensite, and (*d*) cold-worked austenite.

In examining the curves of Figs. 8–15 and the structures of the creep-rupture specimens after test, it was observed that the presence of martensite was generally associated with poor creep properties. Furthermore, the detrimental effect of martensite was approximately proportional to the amount present. The reason for this becomes obvious when it is realized that, at the temperatures used in this investigation, martensite is unstable and decomposes into austenite and carbides. In the martensite-containing steels, whether the martensite was induced on cooling or as a result of cold work, the austenite that subsequently formed at the test temperature could in no way have been affected by the cold work.

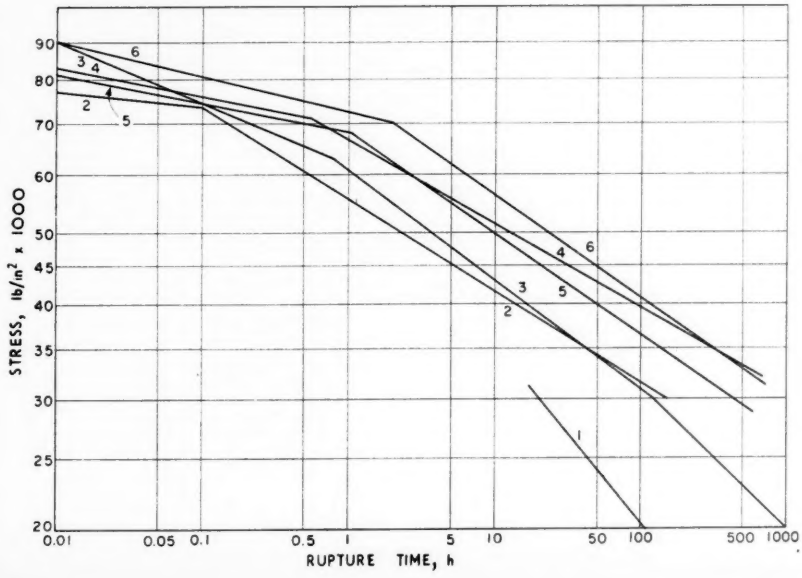


Fig. 11—Comparative creep-rupture plots of 35% cold-worked steels at 1100° F

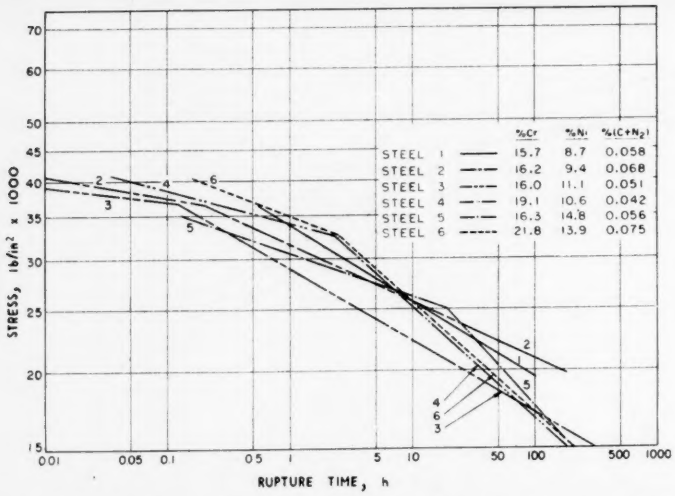


Fig. 12—Comparative creep-rupture plots of annealed steels at 1200° F

It must be concluded then that this austenite is free of cold work. Therefore a cold-worked structure which is partly martensitic will, at some time during the creep-rupture test, be composed both of austenitic regions containing residual strains and regions that are free of them. Also, the greater the amount of prior-martensite the greater will be the volume of 'unstrained' austenite. Hence, the decomposition of martensite must be regarded as eliminating the beneficial effects of cold work in those regions.

Recrystallization of the strained austenite was also found to be closely associated with poor creep resistance. In fact, recrystallized grains were invariably observed under conditions where the optimum levels of cold work were exceeded and resulted in poorer creep-rupture properties (except in the case of sigma formation in steels 4 and 6 at 1200° F, in the 34% cold-worked condition). Once more it was obvious that recrystallization during creep-rupture testing was occurring earlier than would be predicted from static recrystallization studies.[1, 3] Examination of Figs. 4 and 7 shows that wherever recrystallization occurred there was an increase in ductility which served as evidence of recrystallization. On the other hand, when sigma growth occurred, there was a decrease in strength but the ductility did not increase.

As anticipated, the precipitation and coalescence of carbide particles was observed to occur under all conditions of testing. However, because of the complex interaction of the competing processes, it is not possible to explain observed behaviours solely on the basis of carbide precipitation. It appears, as has been shown previously,[11] that while the initial precipitation increased creep resistance, subsequent coalescence resulted in a decrease of creep resistance. The metallographic studies also showed that the austenite

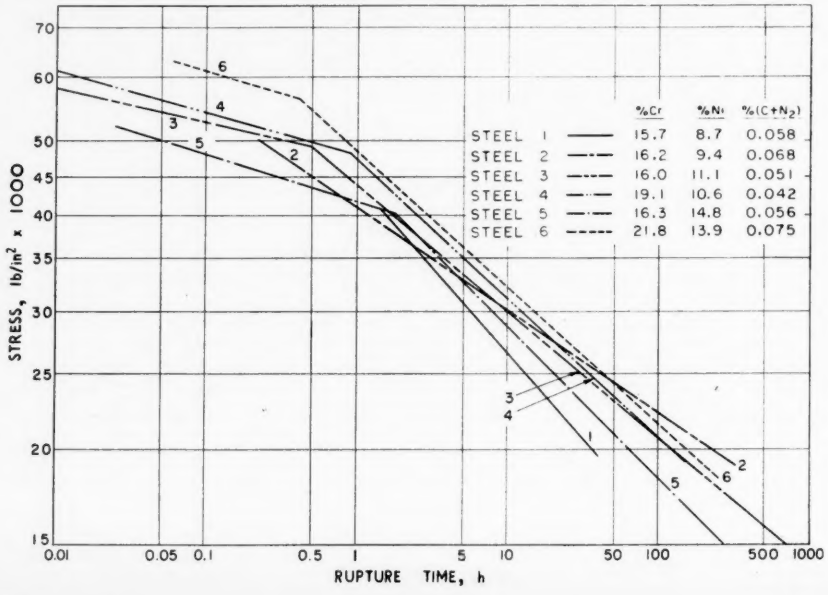


Fig. 13—Comparative creep-rupture plots of 15% cold-worked steels at 1200° F

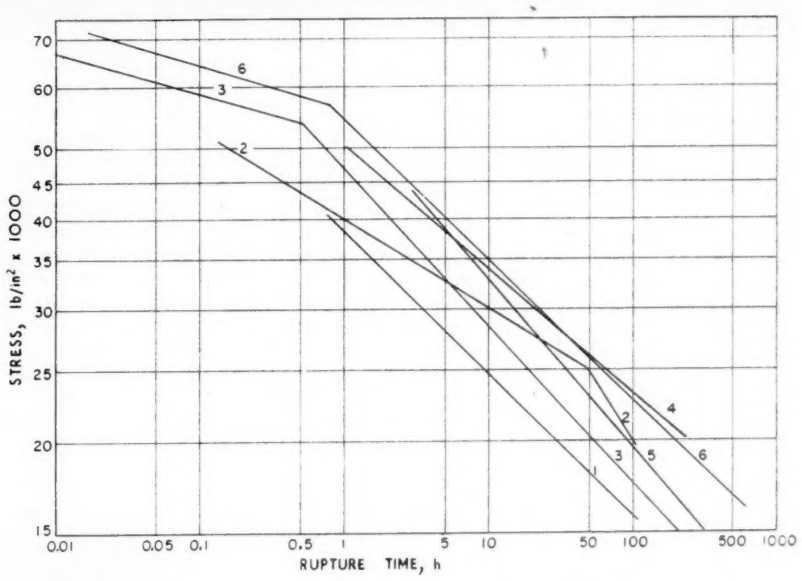


Fig. 14—Comparative creep-rupture plots of 25% cold-worked steels at 1200° F

which formed as a result of the decomposition of martensite contained a greater quantity of carbides than the original austenite.

Comparative Creep-Rupture Results

A complete explanation of the observed comparative results shown in Figs. 8–15 would undoubtedly be quite involved; nevertheless, a satisfactory explanation can be given in terms of most of the observations and some known principles. The first difficulty encountered was that some of the annealed or lightly cold-worked steels (especially steel 2) showed unpredicted variations in creep-rupture properties which are difficult to explain in terms of composition and structure.

Based on the recent work of Monkman, Price, and Grant,[11] and of Hum and Grant,[13] it was shown that the $(C + N_2)$ content contributes greatly to the strength at 1100° and 1200° F for short times, but that the benefits are lost in longer tests, owing to carbide growth. Contributions to strength from chromium are less spectacular than from $(C + N_2)$ but the effects are longer lasting; the benefits are lost, however, when sigma formation becomes significant (at compositions usually above 18–19%). Nickel contributions to strength are small, even for an increase from 6% to 16%.

Based on these observations,[11, 13] which are borne out in the present study, one might expect that these

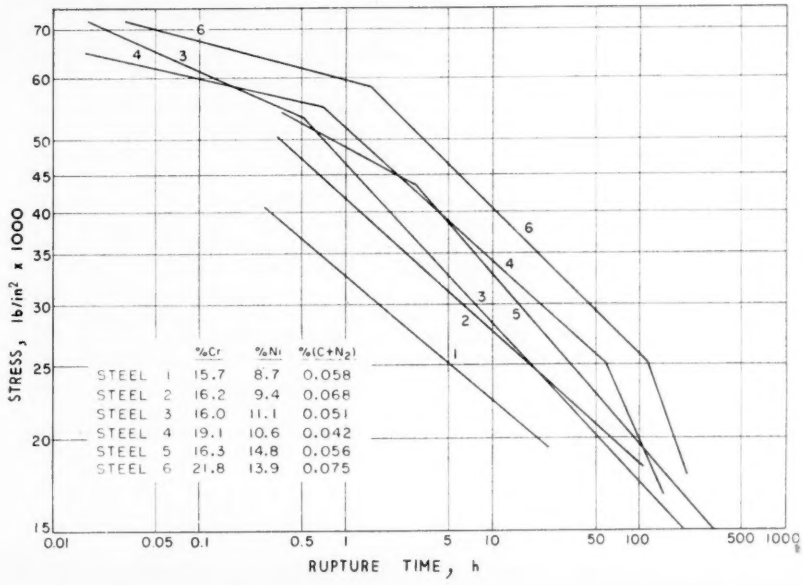


Fig. 15—Comparative creep-rupture plots of 35% cold-worked steels at 1200° F

steels would be stronger in the approximate order 1, 3, 5, 2, 4, 6, with a small difference to be noted among steels 3, 5, and 2, and with the chance that steel 4 might prove stronger than steel 6 in long-time tests at 1200° F because of the more rapid and extensive sigma formation in steel 6.

These considerations would, of course, be expected to be tempered somewhat in the light of martensite-forming tendencies (*see* Table II), and the effect of martensite decomposition on the recrystallization behaviour of these steels; martensite decomposition in itself weakens the structure but it also influences carbide precipitation, as discussed above.

Thus, in examining Figs. 8 and 12, summarizing the tests at 1100° and 1200° F respectively for the annealed condition, it is noted that at 1100° F steel 5 is out of line in tests under about 1 h, and steel 2 is out of line in longer tests up to 500 h. At 1200° F, in short-time tests, only steel 1 is out of line considerably, but in longer-time tests the behaviour is completely unexpected for the entire group of steels. Unfortunately the tests were not made out to 1000 h, where it is expected that a more ordered behaviour might exist. Furthermore, at 1200° F there are complications; carbide precipitation occurs, both from ferritic (martensitic) grains and from austenitic grains; sigma formation takes place at a fairly rapid rate (steels 4 and 6); the higher ($C + N_2$) contents of steels 2 and 6 would also tend to add complications; and the grain size which results on recrystallization, especially in the lower-alloy steels (richer in martensite), would add to the noted differences.

If the steels are now cold-worked, the discrepancies apparent in the annealed steels gradually diminish, being replaced by a logical sequence of behaviour which improves with increasing cold work. In effect, the contribution of cold work to the strength at elevated temperatures becomes more and more significant until the contribution overcomes the effects due to small differences in composition, grain size, carbide precipitation, etc.

If one examines Figs. 9, 10, and 11 (the 1100° F tests) and compares them to Fig. 8, it will be noted that as little as 15% cold work produces a large measure of order of behaviour, steel 2 still being slightly out of line. With 25%, but especially with 34% cold work, the steels follow the anticipated arrangement in the longer-time tests. More important, the full benefits of cold work can be seen in Figs. 10 and 11. In the annealed condition, for a 100 h life at 1100° F, the stress difference between steels 1 and 6 is only about 4000 lb/in²; however, after 34% cold work, the stress for a 100-h life for steel 6 is 41,000 lb/in² (an improvement of 13,000 lb/in² over the annealed condition) and is 20,000 lb/in² greater than for steel 1 (which is now weaker after cold work, owing to recrystallization).

Similarly, if one examines Figs. 13, 14, and 15, and compares them to Fig. 12, it is again noted that increasing cold work achieves the expected arrangement of strength curves for these alloys. At 1200° F, however, more cold work is required to accomplish the rearrangement. Again, as at 1100° F, important gains in strength are achieved by the more stable steels through cold work. Unfortunately, with 34% cold work, the two most highly alloyed steels are so high in chromium that sigma phase growth results at 1200° F in the instability noted in Fig. 15 after about 50–100 h. Steel 5 thus turns out to be the most stable alloy for service beyond about 500 h at 1200° F.

It was indicated earlier that only steels 1, 2, and 3 showed evidence of recrystallization; this observation was verified not only by the weakening shown in the log stress/log rupture-life plots (such as Figs. 2 and 3), but also by metallographic observations and by the ductility values at fracture, as shown in Figs. 4 and 7. These three steels are also the ones which showed martensite before testing. The anomalous behaviour of steel 2 in the annealed condition and after small amounts of cold work can possibly be partly explained by the higher ($C + N_2$) content.

The preferred stainless-steel structure for optimum high-temperature strengthening benefits due to cold work would thus have the following properties:

(i) High recrystallization temperature, which specifically avoids ferrite (martensite) at any stage of processing. This calls for a fully austenitic structure.

(ii) Minimum ($C + N_2$) content (preferably stabilized) to avoid weakening in longer-time tests when the carbides grow in size. Carbide coalescence produces an instability in the usual log stress/log rupture-time plot.

(iii) Not more than about 18% Cr, unless modified by other alloying elements. Too high a chromium content, which results in sigma phase formation, has a weakening effect.

(iv) A balanced nickel content. Nickel in itself does not add measurably to the strength but contributes to a stable austenite.

(v) Alloying additions which do not violate these concepts of a stable austenite of high recrystallization temperature, and which do not make the alloy subject to carbide precipitation or sigma formation.

Room-temperature Properties

Steels 1, 2, 3, and 5 showed a decreasing response to cold work, in that order. The explanation of this becomes apparent when it is remembered that the quantity of martensite in these steels at a particular level of cold work also decreased in the same order (*see* Table II). The deformation introduced by the tensile test caused additional martensite to form; steel 5, however, remained completely austenitic. These results show the expected effect of martensite at room temperature and need not be discussed further here.

The yield-strength curve for steel 4 (Fig. 16) is seen to cross the nearly parallel curves for the fully austenitic steels 5 and 6. As noted in Table II, steel 4 showed a trace of martensite after 34% cold work. Furthermore, the tensile test bars of steel 4 were found to be magnetic near the region of fracture, indicating the additional formation of martensite. On the other hand, steels 5 and 6 remained completely austenitic even under the most severe conditions of deformation. The hardness curves of Fig. 17 confirm the martensite picture discussed above.

CONCLUSIONS

Based on a series of six simple 18–8 stainless steels with M_s temperatures from + 100° F to absolute zero, creep-rupture studies at 1100° and 1200° F for

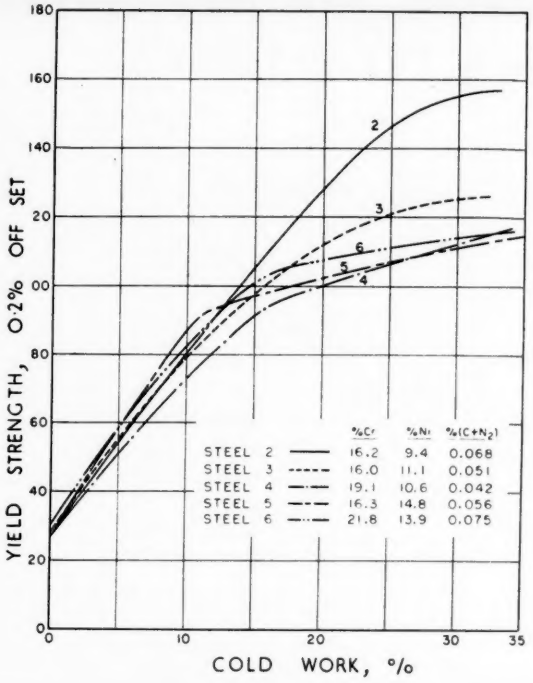

YIELD STRENGTH, 0·2% OFF SET
COLD WORK, %
%Cr %Ni %(C+N2)
STEEL 2 16.2 9.4 0.068
STEEL 3 16.0 11.1 0.051
STEEL 4 19.1 10.6 0.042
STEEL 5 16.3 14.8 0.056
STEEL 6 21.8 13.9 0.075

Fig. 16—Comparative plot of yield strength against percentage cold work

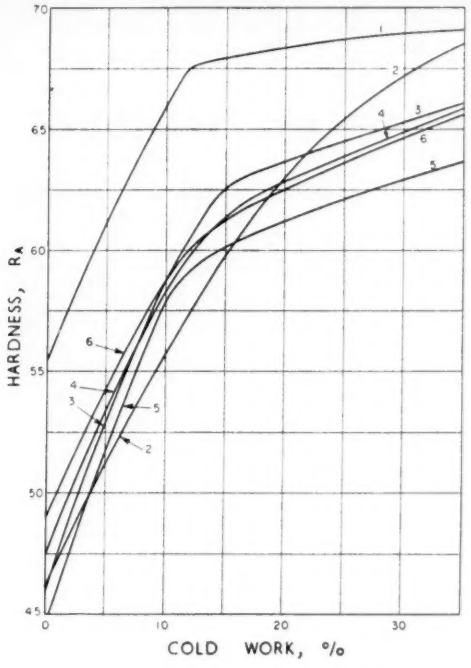


Fig. 17—Comparative plot of hardness against percentage cold work

the annealed steels and three levels of cold work up to 34% permit the following observations:

(1) The higher the M_s temperature, the lower the recrystallization temperature and the weaker the alloy in creep rupture in the annealed but especially the cold-worked condition. This is particularly true in the longer-time tests.

(2) The stable austenitic alloys show the best response to cold work in creep-rupture and do not recrystallize at 1200° F or lower in less than 1000 h.

(3) Fully austenitic alloys are subject to weakening in long-time tests, especially above 1200° F, if carbide agglomeration occurs or if sigma growth occurs. These weakening reactions suggest selection of low ($C + N_2$) alloys containing sufficient nickel for austenite stabilization, and chromium levels which are high but avoid sigma formation.

(4) Low creep-rupture ductility is associated with strengthening through cold work, but important increases in ductility occur with recrystallization during test.

(5) The strength improvements with cold work have the effect of making more predictable the high-temperature behaviour of the same steels, which show considerable variation of properties in the annealed condition.

(6) At room temperature, the improvement in tensile properties shows that strength improves with increasing prior-martensite.

Acknowledgments

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Oxygen Lancing of Pig Iron and Subsequent Fume Treatment with a Pease-Anthony Venturi Scrubber

AT DORMAN LONG (STEEL) LTD., REDCAR WORKS

By P. K. Gledhill, B.Met., Ph.D., P. J. Carnall, B.Sc., M.Inst.F., and K. H. Sargent, M.Sc., D.I.C.

SYNOPSIS

The Pease-Anthony Venturi scrubber is described and its mode of action discussed for the removal of iron oxide fume during oxygen lancing.

A series of trials has been carried out in which the scrubber was used to clean the gases evolved from blast-furnace metal in a ladle during desiliconization with oxygen. The fume solid is similar to that studied elsewhere i.e. about 85–95% iron oxides with the balance in compounds of silicon, manganese, phosphorus, and sulphur. It is thought that most of the particles are of submicron size and the total weight is about 70–100 lb evolved during a 20-min blow from 30 tons of metal. It has not been possible to show any effect of batch size or of oxygen flow-rate on the rate of emission of solids but there are qualitative indications that the total weight of dust evolved is related to the amount of air drawn into the hood.

As constituted in this test, the Pease-Anthony scrubber removed 99·5 + % of the fume, reducing the concentration to 0·1–0·2 gr/ft³. It is thought probable that by using increased throat velocities and water-rates in the Venturi the outlet dust concentration could be reduced to less than 0·1 gr/ft³. Significant removal of fume was effected in a simple spray tower which is normally incorporated as a precooler-saturator before the scrubber when treating gas at a high temperature. The mechanism of this removal is not clear. It may depend either on the larger particle size of some of the particles or on the high temperature of the inlet gases. Qualitative evidence suggests that a condensation of water from the vapour phase round the particles is a factor in the mechanism of cleaning in both precooler and scrubber.

At the rate of oxygen input used in these tests (275–400 normal ft³/min), the actual gas driven off from the ladle should not exceed 250 normal ft³/min. This gas seems to be mainly composed of carbon monoxide, produced by the decarburization of the iron, and, if mixed with air at a high temperature, presents an explosion hazard.

Two possible designs for a commercial unit are presented and discussed. One of these provides for an air-tight hood over the ladle to avoid explosive mixtures and the second provides for a large ingress of air with thorough mixing to reduce the carbon monoxide concentration below the explosion limit and cool the gases at the same time.

An economic assessment of these two designs reveals that the cost of scrubbing in the first case should not exceed 3·48 pence per ton while in the second case it should not exceed 6·90 pence per hour. The final decision between these two designs will be a case of balancing the practical difficulties of an air-tight hood against the increased cost per ton in the case where a larger volume of fume is treated. In any case the cost per ton appears to be much less than that quoted for similar operations. 1343

Introduction

OF ALL THE WET SCRUBBERS which have been considered for dealing with iron oxide foundry fumes, the Pease-Anthony Venturi scrubber seems to have been given the most enthusiastic reception. Thus, Jones[1] reporting oxygen injection for remelting scrap in the open hearth in the U.S.A., Leroy[2] describing oxygen lancing in the ladle in France, and Davis[3] recording operating details of oxygen lancing in a steel convertor at Dofasco, Canada, all quote efficiencies of above 95%. On the other hand, some authors (see references 4 and 5) consider that the power consumption of this type of scrubber is excessive.

In the U.K., no satisfactory solution to the fume problem has been reported and the wide application of oxygen lancing depends to some extent on the development of a satisfactory method of removing the fume produced. When an opportunity arose therefore, to participate in trials arranged by Dorman Long (Steel) Ltd., it was regarded as being of considerable interest to determine the technical and economic merits of the Pease-Anthony Venturi scrubber under semi-production conditions.

The trials were held at the Redcar works of Dorman Long (Steel) Ltd., in conjunction with The Power-Gas Corporation Ltd., who manufacture the scrubber in the U.K., and The British Oxygen Co., Ltd., who supplied and metered the oxygen used.

Units

The following units will be used in this paper unless other conditions are specifically mentioned:

(i) All gas volumes will be expressed as normal cubic feet (i.e. measured dry at 0° C and 760 mm of mercury)
(ii) Temperatures will be expressed both in °C and °F
(iii) Particle sizes will be expressed in microns (μ)

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Dr. Gledhill is with Dorman Long (Steel) Ltd., Mr. Carnall is with The Power-Gas Corporation Ltd., and Mr. Sargent is with The British Oxygen Co., Ltd.

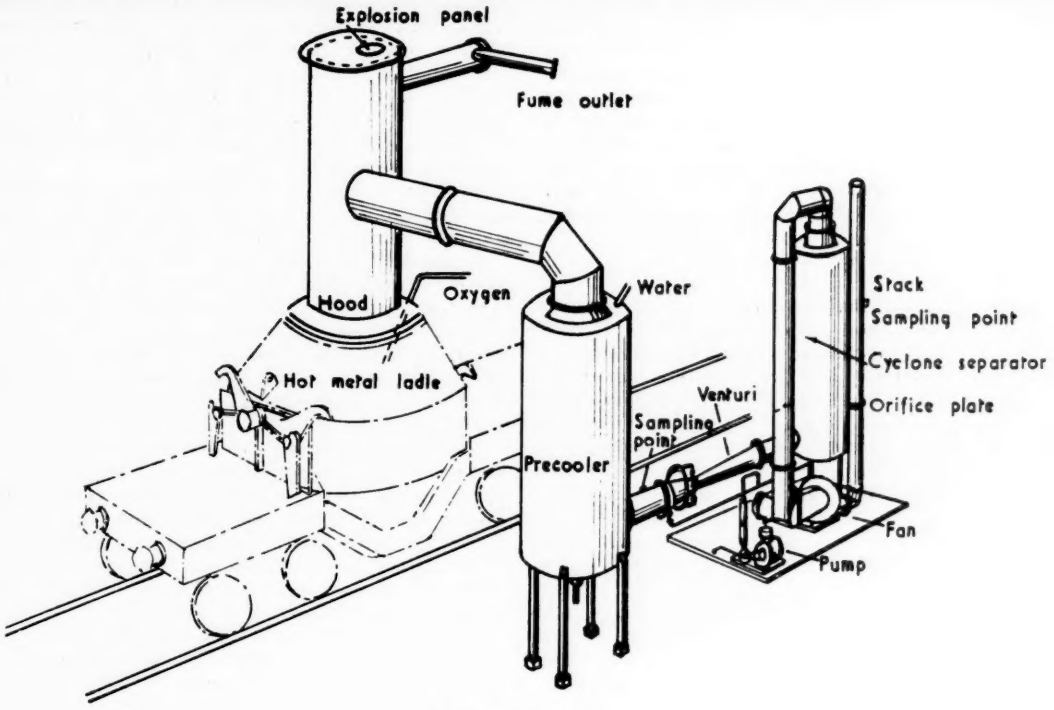

Fig. 1—Test layout

(iv) Fume concentrations will be expressed in grains per normal cubic foot
(v) Water quantities are expressed as Imperial gallons (= 0·83 × U.S. gallons).

EQUIPMENT

The experimental layout and equipment are illustrated in Figs. 1, 2, and 3. The essential components are:

(i) A 55-ton Kling-type ladle
(ii) A hood to collect the fume
(iii) A spray cooler
(iv) A Pease-Anthony Venturi scrubber
(v) A cyclonic separator
(vi) A fan.

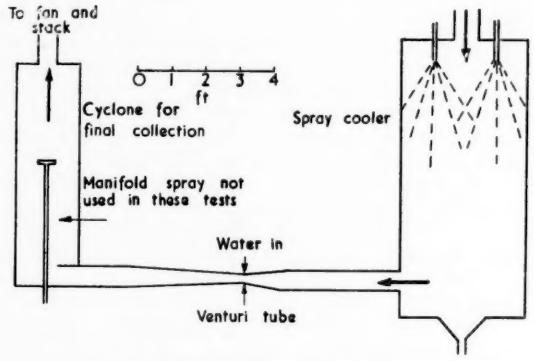

Fig. 2—The Pease-Anthony Venturi scrubber with the precooler used in these tests

Hood

For these experiments, a ladle hood was needed which would fulfil the following requirements:

(*a*) It would allow 500–600 ft³/min of the fume-laden gas to be drawn off into the pilot plant whilst discharging the remainder to atmosphere.

(*b*) It would minimize the amount of air drawn into the ladle, since this would decrease the volume of gas to be treated and possibly decrease the actual generation of fume.[3]

The design initially adopted is shown by the full lines in Fig. 3, subsequent additions being indicated by dotted lines. The size of the main chimney *A* was determined on the basis of the volumes of gas handled at Mondeville[2] and, as was expected, this

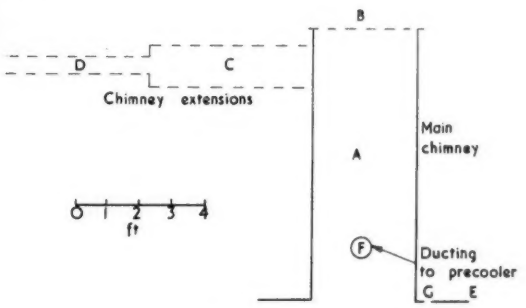

Fig. 3—Ladle hood and chimney

proved to be considerably overestimated. Subsequent trials were carried out with the chimney closed at *B* and with the narrow side-arms *C* and *D* successively added to vent the excess fume. The square, flat plate *E* was placed on top of the ladle. The joint between the plate and the ladle top was made with bricks, metal plates, and fireclay. The lance was introduced through the slit *G*. The fume under test was drawn off through the side-arm *F*, which was joined to a precooler by means of a telescopic coupling, the seal again being made effective with fireclay.

Precooler

It was estimated that the outlet temperature of the gases from the hood varied from 300° to 1200° C (570–2200° F) depending on the extent of combustion of carbon monoxide. Dry gas at 1000° C will absorb about 3 gal of water per 1000 normal ft³/min of gas and decrease to less than half its original volume in saturating. A precooler was therefore installed to saturate partially the gas and reduce the temperature to a level at which the change in gas velocity in the throat would not be prohibitively large, and the water quantity used for saturation in the throat small. Final saturation would then be quickly attained in the Venturi throat.

The precooler (Fig. 1) was a simple vertical cylinder of mild steel, from the roof of which water was sprayed through four nozzles. The effluent flowed away continuously from the conical base at 5–10 gal/min.

Pease-Anthony Venturi scrubber

Three types of Venturi scrubber have been reported in industrial practice,[4] and, of these, two operate with an injection of liquid along the axis of the Venturi, whilst the third has a circle of jets entering from the sides of the throat, usually at right-angles, to give an apparently complete curtain of water. This latter type, in combination with a suitable wet or dry cyclone as the collecting plant, is known as the Pease-Anthony Venturi scrubber, and is illustrated in Fig. 1.

The operation of the scrubber involves the wetting of the fume particles in or beyond the throat, with the subsequent formation of droplets which are sufficiently large to be collected by the cyclone. The process is usually described in the following terms[1, 6] "The stream of fume-laden gas 'collides' with a curtain of liquid at the Venturi throat, where the liquid is briefly but violently accelerated and disrupted. The fine particulate matter in the gas is wetted by the finely atomized liquid droplets, and considerable coalescence of the droplets occurs in the diverging section." The mechanisms by which these processes take place are far from clear, and may, indeed, be different under different circumstances. Thus, the final coalescence "is thought to be mainly due to collision and impaction, but diffusion, molecular bombardment, electrostatic effects, and condensation may all be involved ".[1, 6]

One of the major characteristics of the scrubber, of course, is the high gas velocity at the throat. Thus, values of 200–500 ft/s are quoted in the literature,[1, 4, 6, 7] whilst in the present tests about 250 ft/s was usual. These velocities give rise to considerable turbulence, and the resulting increased impaction undoubtedly accounts for much of the efficiency in the case of particles larger than 1 μ. Smaller particles, however, become decreasingly susceptible to turbulence and impaction, and below 0·5 μ the main process of wetting occurs by Brownian movement, or diffusion.[4, 7] With this type of fume, therefore, turbulence is not likely to make a major direct contribution to the collection efficiency.

An indirect effect is the splitting-up of the water into tiny droplets; it has been suggested that there is an optimum size of droplet for the wetting process.[4, 7] Unfortunately, it is not clear what size this should be since some authors quote values equal to the size of the particles to be collected (submicron in this case) and others[4, 8] suggest figures ranging from 10 to 100 μ. In neither case, however, do the high reported efficiencies appear to be explained since the droplets formed in the Venturi throat are rarely less than 20 μ in diameter.[4, 7]

Collision of the fume with a continuous barrier of water provides an easy pictorial image of the process, but of course, the 'curtain' cannot be a complete barrier during actual gas flow since this would necessitate rapid solution of large quantities of gas in the water. The best that can be expected is that small gas bubbles will become enmeshed with the liquid and pass through in this way.

Electrostatic charges may be expected, due to the extremely violent disruption of the water droplets,[7, 9] and it is possible that submicron particles will unite more readily with larger droplets under these circumstances. The origin of the necessary complementary charges on the fume particles is obscure, however, and it is probable that a more important function of the electrostatic effect is to cause coalescence of the primary droplets.

The last suggested mechanism, that of condensation, may be particularly appropriate to foundry processes, where the very hot gases are usually cooled to 60–160° C by means of a spray tower before the scrubber.[3, 6] Because of this, they become saturated with water at a relatively high temperature, and in being cooled by the water at the Venturi and by the expansion which takes place subsequently, deposit water droplets on any nuclei present. Such water droplets would be sufficiently large to be collected by the cyclone.

Condensation is unlikely to be complete during the short time of passage through the collecting equipment, and it is not surprising that a white plume of 'steam' has been seen issuing from the final stack.

The Pease-Anthony scrubber used in these trials (Figs. 1 and 2) was a pilot unit constructed by The Power-Gas Corporation Ltd., the approximate dimensions being indicated in Fig. 2. The circular Venturi throat was about 2½ in. in diameter, and this was supplied with 2–4 gal/min of water by three jets around its circumference. This water was delivered from a reservoir by a gear-type pump. The gas flow was created by a fan immediately before the final stack and was regulated and measured by means of a damper and an orifice plate respectively.

Cyclonic Separator

The outlet fume from the Venturi scrubber entered

the cyclone tangentially. A vortex was created, both by the tangential inlet and the ' core-buster '—the horizontal disc shown in Fig. 2. The water droplets, containing agglomerated particles of the dust, were flung out to the sides of the cyclone by centrifugal force and fell to the bottom of the cyclone to an effluent drain. The gases passed out of the top, through a flow straightener, to the centrifugal fan and thence to the stack. The fume quantity drawn off through the scrubber was controlled by a damper in the stack (after the fan)—see Figs. 1 and 2. The gas make was measured with an orifice plate placed in the line between cyclone and fan.

PROCESS DESCRIPTION

Metal Treated

For each trial, about 30 tons of metal were tapped into a Kling ladle containing 5 cwt of limestone, a further 10 cwt being added during filling. In addition, 4 cwt of soda ash were added for the last two tests in the series. Metal was tapped from either of the two blast-furnaces as convenient, and in both cases the initial composition was very variable. Table I shows the range and mean analyses.

Injection of Oxygen

Oxygen was supplied from a bank of three to five 2000-ft^3 cylinders to a $\frac{1}{2}$-in. mild-steel lance, which was manually fed down to the slag/metal interface, judging the position by ' feel.' The gas flow was estimated in the B.O.C. portable apparatus by means of an orifice plate, but for some of the trials this was unreliable. The total volume of oxygen injected was calculated from the fall in pressure inside the cylinders.

No correction was made in these calculations for deviations from Boyle's law, and additional errors were created by not allowing the cylinders to warm up completely to ambient temperature before taking the final pressure measurements. Fortunately, these errors operate in opposite directions, and it may be estimated that for a fall in temperature of roughly 20° C, the errors will cancel out. Since the magnitude of the Boyle's law error is about 6%, the errors of individual measurements will have been at least $\pm 4\%$.

The oxygen flow rate used was 275–400 ft^3/min and the time of injection was 20–25 min.

Test Procedure

After filling the ladle, the hood was placed on top of the ladle by the cast-house crane, the ladle moved to the experimental site and connected to the saturator. The pouring spout was bricked up and the joint between the top of the ladle and the base-plate was sealed with fireclay. The fan for the scrubber was started and when the gas flow through the scrubber had been set by means of the stack damper, water was fed to both Venturi and precooler. The water to the Venturi was supplied by a small gear pump and metered through a rotameter at 2–4 gal/min. The precooler water came from mains supply. The oxygen lance was pushed into the ladle with oxygen on and the fume appeared immediately the lance had penetrated the skull. The blow lasted 20 min, after which the lance was removed. The scrubber was run until all the fume had been removed.

Table I

ANALYSES OF THE METALS BEFORE OXYGEN LANCING, %

	Furnace 1		Furnace 2	
	Mean	Range	Mean	Range
Si	0·56	0·31 –0·76	0·66	0·25 –1·06
Mn	0·90	0·70 –1·10	1·15	0·91 –1·55
C	3·92	3·59 –4·15	4·00	3·61 –4·15
S	0·072	0·046–0·099	0·046	0·024–0·083
P	0·77	0·72 –0·83	1·35	1·20 –1·50

ANALYTICAL PROCEDURE

Measurement of Fume Volume

Attempts to measure the velocity and hence the volume of the excess fume gases by means of a pitot tube were unsuccessful. When the fume was being vented through the main chimney *A*, no differential pressure-head could be recorded, and even when the narrow side arms *B* and *C* were used, the readings were only of the order of 0·02 in. w.g. These readings were not regarded as sufficiently accurate to be dependable. It is conceivable that some blockage of the pitot probe occurred by deposition of the fume, but it is unlikely that this factor would account for the low values, since closure of the more susceptible ' static ' holes would give rise to high readings. Other semi-quantitative estimates of the fume volume were made by visual observation of the behaviour of the fume cloud under the influence of wind, using the plume from the Venturi stack as a standard.

Fume Sampling

In the earlier tests, gas samples were drawn through a probe in the centre of the ducting and passed through a Stillite filter[10] (condensation of water being reduced by heating the filter with a heating tape), then through a condenser to remove excess water, and finally through a gas-meter. In the later tests, a wet filter[11] was used ahead of the Stillite filter and this successfully removed acidic sulphur compounds in the gas together with the majority of the dust, the Stillite filter removing the smaller dust particles.

After use, the Stillite filter was dried to constant weight (up to 48 h at 105° C) and the collected fume estimated by difference. To this was added the weight of the filtered and dried solid from the scrubber, when used, and the total concentration was calculated in grains per normal cubic foot of gas.

In the first experiments, no attempt was made to sample isokinetically, on the assumption that this refinement was unnecessary when dealing with submicron particles. It seems likely, however, that some wetting of the fume was occurring after the final cyclone, so that the particles were actually much larger than they had been originally; in view of the fact, therefore, that sampling velocities were so very different from those of the gas stream (a ratio of about 1 : 20 was used on one occasion) these early results are probably badly in error. They were, indeed, unexpectedly high, and it was only in the last three tests that the necessary refinement of technique

Table II

BEST OPERATING CONDITIONS FOR THE SCRUBBER

Test No.	Mean Venturi Inlet Temp., °C	Orifice Temp., °C	Fume (Sat'd) at Orifice Conditions, ft³/min	Water Rate l., gal/1000 ft³ gas	Pressure Drop across Venturi, in. w.g.
11	85	48	515	4·2	13·5
12	86	48	515	4·2	13·5
13	Temps. varied widely		515	4·2	13·5
14	92	53·5	515	5·0	15·5
15	66	53	515	5·0	15·5
16	84	54	600	5·3	25

was approached. The 0·1 gr/ft³ indicated by these last three tests was still high in comparison with those quoted in the literature (e.g. Jones[1] quotes final dust loadings of 0·03–0·06 from oxygen lancing of open hearth furnaces, with particle size 0·08–1·0 μ).

Effluent Samples

In order to check the amounts of fume removed by the spray precooler and by the final cyclone, analyses of the respective aqueous effluents were obtained. Aliquot portions (approximately 100 ml) were taken from the drainage pipes at equal time intervals over the whole period of test until the effluent was clear and were bulked to give one large sample from each source. These were analysed for total solids, Fe, SiO_2, etc.

Temperatures

Temperatures were taken at the inlet and outlet to the Pease-Anthony scrubber and these are shown in Table II.

Gas Analyses

During the later tests, cumulative samples of the gas stream were obtained by withdrawing aliquot portions at 1 min intervals into a single gas-sampling flask (about 500 ml capacity), initially filled with mercury.

Metal Analyses

Metal samples were taken during filling of the ladle and while emptying the ladle after oxygen lancing.

RESULTS

Operating Conditions for the Scrubber

The conditions of operation of the scrubber for the last six tests are shown in Table II. During the first ten tests different water rates and throat velocities were tried, but as the dust-sampling technique was still being developed, visual observation only was used to determine the efficiency of scrubbing. The results shown in Table II are felt to be representative of the best operating conditions used in these tests.

Efficiency of Fume Removal

The plume discharged from the pilot-plant stack bore a striking contrast at all times to the cloud which rolled from the main chimney. Whereas the colour of the latter was always a very deep brown or black, that of the former varied from a thin wisp of grey to a broad plume of near-white. It was evident that from a visual point of view the performance of the plant was quite satisfactory.

Analytical confirmation of this opinion, however, was lacking in the early trials owing to various experimental difficulties with the fume sampling, and the only results which are available are those for the last six tests, these being quoted in Table III. The dust loadings shown in Table III are for the scrubber operating conditions of Table II.

These results are based, in the main, upon the aqueous effluent analyses and the outlet fume samples, but in the last two tests samples were also taken of the inlet gas to the Venturi. These latter were in good agreement with the former, so that average figures have been quoted in the table.

It will be seen that not only is there a highly efficient removal of fume in the Pease-Anthony scrubber, but also that a marked cleaning occurs in the precooler. The overall effect of the plant is most easily appreciated from the last column of the table, showing the percentage efficiency, but it is more important to consider the absolute concentration of fume discharged to atmosphere (column 4).

The first results quoted are rather higher than was expected on the basis of the visual appearance of the plume. As mentioned earlier, in Tests 1 to 10 the dust-sampling technique was still being developed and the results of tests 11 to 13 are possibly less reliable than those of 14 to 16.

Volume of Fume Emission

It is most important from both practical and theoretical standpoints to estimate the total volume of fume emitted, but, as indicated above, accurate measurements were difficult to make. Pitot tube readings on the gas flowing from the main chimney *A* or taken from its 15-in. and 6-in. appendages (*B* and *C*) were of the order of 0·02 in. w.g.

The paradox of a ' constant ' velocity with changing diameter is explained by what was apparent to all observers, that as the ladle hood became progressively more closed in, the actual volume of fume decreased. This is quite in accord with speculations that much of the fume volume was inspirated air and this inspirated air would decrease as the chimney diameter was decreased.

In order to obtain a more reliable estimate of the

Table III

ANALYTICAL DATA CONCERNING THE EFFICIENCY OF FUME REMOVAL

Expt. No.	Fume Concentration, gr/ft³			Percentage Efficiency		
	Before Precooler	Before Venturi	In Final Stack	Pre-Cooler	Pease-Anthony scrubber	Combined
11	48·1	21·0	0·37	56	98·2	99·2
12	36·5	20·7	0·20	43	99·0	99·5
13	46·4	36·2	0·23	22	99·4	99·5
14	48·1	26·9	0·12	44	99·6	99·8
15	53·1	15·2	0·10	72	99·3	99·8
16	39·1	14·9	0·14	62	99·1	99·6

total amount of fume given off from the ladle the Pease-Anthony scrubber was operated above its rated capacity of 500 ft³/min during the final test. The base-plate of the hood had buckled by this time and some air was being drawn into the hood. During this test, the quantity of fume seen to emerge from the side-arm of the hood was negligible (i.e. almost all the fume was being drawn through the scrubber). The volume handled by the scrubber was measured at the orifice plate as 600 ft³ at 50° C (saturated), corresponding to about 450 ft³/min at normal conditions (dry, 0° C, 760 mm of mercury) and the gas analysis taken indicated that about half of this was inspirated air. This gave an estimation of 200–250 normal ft³/min of fume emitted from the ladle in the absence of air.

The pitot reading taken in the 6-in. appendage under similar conditions of draught in the hood gave an estimate of 150–200 normal ft³/min of fume emitted from the ladle. It is therefore probable that the greatly increased fume quantity observed with the more open hood was due to an increase in the volume of inspirated air consequent on a higher chimney draught.

The present evidence, of course, does not exclude the possibility that the variations in fume emission were due to changes in metal composition or to some unforeseen factors, but is is considered likely that the above explanation is the correct one. As a result, an estimate of 250 normal ft³/min of fume emitted from the ladle in the absence of air is probably a conservative figure (i.e. on the high side).

Weight of Fume Emission

The actual weight of solid fume passing through the saturator may be estimated from the analyses quoted in Table II; they are presented in various ways in Table IV.

The additional weight of fume discharged from the main chimney can only be estimated from the above approximate considerations of volumes, and would appear to be up to about 60% of that entering the saturator. The total fume evolved, therefore, is of the order of 0·1% of the weight of the metal. This quantity is distinctly lower than has been reported elsewhere.

Table IV

WEIGHTS OF FUME ENTERING THE SATURATOR

Test No.	Weight of fume, lb			
	Total Weight	per 100 lb Metal	per 1000 ft³ Oxygen	per 100 lb Metal per 1000 ft³ Oxygen
11	63*	0·075	9·6	0·0114
12	48*	0·069	6·9	0·0092
13	61	0·097	8·4	0·0133
14	63	0·095	9·6	0·0145
15	64	0·098	9·3	0·0142
16	57	0·065	8·5	0·0097

* These two weights have been corrected *pro rata* for the fact that the blows were only 19 min in duration, compared with 20 min for the others

Table V

COMPARISON OF FUME EMISSION

Plant Location	Tons Treated per Blow	Fume Treated, normal ft³/ton	Dust Collected, lb/ton
Redcar	30	456	2–3
Mondeville[2]	35	4260	10
Dofasco[3]	45	58,600	60

For example Table V above compares the fume given off in these tests (Redcar) with some reported values in the literature at Mondeville[2] and Dofasco.[3]

It should be pointed out that the Dofasco figures refer to oxygen blowing in a convertor installation but it is possible that the mechanism of fume release is similar in this case.

Although Table IV shows that the fume formed bears roughly constant proportions to the melt weight, to the oxygen rate, and to the oxygen rate per unit metal weight, the variations do not seem to be conditioned by differences in these factors since the relevant correlation coefficients are extremely low ($r < 0{\cdot}1$). However, Table V suggests that the weight of fume emitted is dependent on the amount of air drawn into the hood and, as stated above, qualitative observations during the tests confirmed this.

Nature of the Fume Emission

Qualitative Observations

The cloud of fume produced during blowing was extremely dense, but the deep colour was subject to some interesting variations in hue which may later be of theoretical importance. Whereas the fume emitted from the first broad open chimney was mainly brown in two tests out of three (and possibly also in the third), it was mainly black when discharging from the narrow, horizontal side-arms. This latter colour did not appear until a few minutes after the beginning of blowing, the first emissions always being cream, fawn, orange, and brown. The normal colour experienced in industrial blowing, of course, is brown, and the black seems to have been a result of the exclusion of most of the entrained air. The colour changes of the fume are probably analogous to the colour changes experienced in the controlled roasting of iron oxide to obtain pigments.

Measurements of the fume temperatures in the main chimney or its side-arms ranged from 200° to 1200° C. It was of some interest to note that whereas in the early trials, with the main chimney open, the connecting main to the saturator frequently became red-hot, this was not so when the modified hood was used subsequently. This was probably due to differences in the extent of combustion of the carbon monoxide evolved, since strong flames were seen coming from the chimney on some occasions. Restriction of the amount of entrained air, far from raising the temperature by reducing the dilution of the hot gases, may actually have been beneficial in reducing this heat of reaction. Unfortunately this point cannot be considered to be proven, since there was a general

Table VI

MEAN ANALYSES OF THE DRIED SOLIDS FROM THE AQUEOUS EFFLUENTS

Analysis	Saturator			Venturi		
	Mean	Range*	No. of Samples	Mean	Range*	No. of Samples
Total Fe	64·9	62·7 –67·1	10	64·4	61·4 –67·4	9
Fe +++/Total Fe	0·628	0·38– 0·87	10	0·620	0·41– 0·84	9
Fe oxides	89·4	85·2 –93·5	10	88·7	85·0 –92·3	9
SiO_2	2·3	0·9 – 3·8	8	2·3	0·5 – 4·1	7
P_2O_5	3·0	0·7 – 5·3	6	3·8	0·8 – 8	4
MnO	2·1	0·7 – 3·5	8	2·1	0·8 – 3·4	7
S (as SO_3)	1·5	0·1 – 2·9	6	1·6	0 – 4·0	4
Loss on ignition	1·3	0 – 3·7	5	1·5	0 – 3·5	5
Total	99·6			100·0		

* 95% of the observations will be between these limits

reduction in rate of oxygen flow in the second half of the trials.

Nature of the Fume Particles

The analyses performed on the solids filtered from the aqueous effluents are summarized in Table VI and although it is probable that some increase in the degree of oxidation occurred in contact with water, these may be regarded as approximations to analyses of the original fume.

Although no data will be presented here, it may be mentioned that the analyses were tolerably consistent between saturator and Venturi samples during each experiment, although the variations from test to test were greater. For example, there was a tendency for the degree of oxidation of the iron to increase as the efficiency of oxygen utilization decreased, but the correlation coefficients were not large ($r = -0{\cdot}60$ to $-0{\cdot}68$; $p = 0{\cdot}05$ to $0{\cdot}07$). These variations, however, are comparatively unimportant.

It will be seen that the fume is predominantly oxide of iron, and that the material extracted by the saturator is chemically very similar to that removed by the Venturi. Generally speaking, the analyses are similar to those obtained in experimental work at the Research and Development Centre of the British Oxygen Co. Ltd. and to values quoted by Guthmann[12] for fume from the oxygen lanced, open-hearth furnace. The proportion of 'impurities' is generally higher than the 3% quoted by Leroy.[2]

Table VII

ANALYSES OF CUMULATIVE FUME-LADEN GAS SAMPLES, %

Test No.	13	14	15	16
CO_2	27·3	23·2	40·6	26·3
O_2	7·7	9·1	12·6	6·6
CO	21·6	15·7	3·4	10·7
H_2	0·6	0·2	0·2	0·2
N_2	42·8	51·8	43·2	56·2

The Nature of the Supporting Gas

The analyses actually obtained on the cumulative fume-laden gas samples are shown in Table VII.

The composition of the gas as quoted in Table VII is curious in that whilst some combustion of CO to CO_2 has obviously taken place (the ladle temperature being well above the ignition point) the reaction is not complete.

Some of the CO_2 present could have been formed by a delayed breakdown of the limestone. Since the decomposition temperature of the latter is about 900° C, its breakdown could only have been delayed if large lumps became supported in the relatively cool mass of the crust on top of the ladle, but in view of the agitation during filling and the delay of about 45 min before lancing, it seems unlikely that this will have provided more than a very small proportion of the gas evolved during oxygen injection.

If this hypothesis is rejected, and it is assumed that all the CO_2 was formed by combustion of CO, the initial composition of the mixture may be calculated. The results recorded in Table VIII assume the composition of air to be 79% N_2 + 21% O_2.

It will be observed that despite the care taken in sealing the ladle hood, during the last four tests when these samples were taken, about half the initial gas volume was actually air. This was probably due to the buckling of the base-plate of the hood, which occurred about this time, owing to the excessive local heating and the thinness of the plate. A moderately constant proportion of CO was present and a variable amount of excess oxygen.

Table VIII

CALCULATED COMPOSITIONS OF THE INITIAL GAS MIXTURES IN THE LADLE, %

Test No.	13	14	15	16
CO	43·1	34·9	36·6	32·7
O_2	8·8	6·1	17·7	4·3
H_2	0·5	0·2	0·2	0·2
Air	47·6	58·8	45·5	62·8

A final small point of some interest that does not appear in the gas analyses was the fact that noticeable quantities of sulphur gases were evolved during the two melts in which soda-ash had been added.

DISCUSSION AND DESIGN RECOMMENDATIONS

Efficiency of the Saturator as a Scrubbing Medium

From Fig. 4 it appears possible that the efficiency of the precooler as a scrubber is related to the rate of water-flow (the correlation coefficient is 0·86, with a probability of 0·03). However, it must be remembered that only a restricted range of water flow-rates were used in the tests. The efficiency of over 60% shown in the graph occurred in a test in which the oxygen lance had not penetrated the metal surface and it may be that the high efficiency here is due to a larger particle size of fume than in the other tests.

Stairmand[8] has suggested that the efficiency of this type of tower with submicron fume is 10–50%, and similar efficiencies have been experienced when scrubbing zinc oxide fume of submicron size.[13] Furthermore, Stairmand has suggested that in all wet scrubbers of the type used in both saturator and Venturi scrubber, the efficiency of scrubbing is related to the gas velocity rather than to the water-rate. As a result, it is felt that the 60% scrubbing efficiency experienced in these tests represents the maximum efficiency likely to be achieved by the saturator for this application.

Vaporization of water in the hot roof followed by condensation in the cooler base provides a possible mechanism for the scrubbing achieved in the saturator. It is probable that complete saturation was not achieved in the saturator but owing to the extremely fast rate of cooling local supersaturation may well have occurred, giving rise to local condensation of droplets round the particles. With the excess of water present, these droplets would not necessarily be re-evaporated.

Efficiency of the Pease-Anthony Venturi scrubber

Table III indicates that the scrubber as used for these tests was capable of cleaning the fume down to an outlet dust loading of 0·1 gr/normal ft³. Lower outlet dust loadings have been reported for similar applications using this scrubber, e.g. for oxygen lancing of an open-hearth furnace with a particle size of 0·02–0·50 μ and an inlet dust-loading of 1–6 gr/ft³, an outlet dust-loading of 0·01–0·07 gr/ft³ is reported.[1] Also for oxygen lancing of a steel converter at Dominion Foundries and Steel Co. Ltd., Hamilton, Ontario, a reduction from 4 gr/ft³ at inlet to 0·04 gr/ft³ at exit is reported.[14]

There is an important difference between these last two cases and the tests carried out here. The Venturi pressure drop used was 25–30 in. in both above cases, while the pressure drop used in most tests was 15 in. w.g. This higher pressure drop corresponds to higher Venturi water-rates and higher throat velocities. For a given particle size scrubbing efficiency is a function of the pressure drop, there being a limiting value of efficiency above which pressure drop has a negligible effect. It is also understood that for a given scrubber efficiency the pressure drop required is a function of the particle size. It may well be that the fume particles from an open-hearth furnace and converter are smaller in size than those from a pig iron ladle, but recent tests with this same pilot plant on an open-hearth furnace have not confirmed this. If this possibility is rejected, it is likely that the limiting value of scrubber efficiency was not reached in these tests.

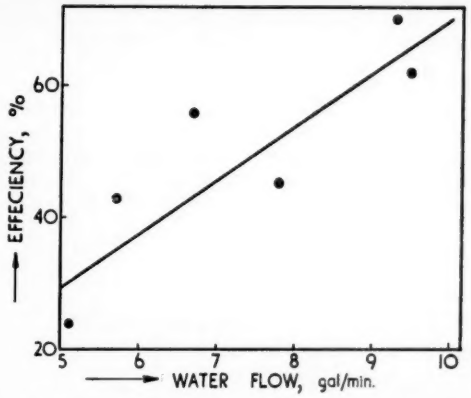

Fig. 4—Effect of water flow rate on the efficiency of the precooler as a scrubbing unit

As a result of these observations and until there has been more opportunity to test the scrubbing efficiency with higher pressure drops it is recommended that future installations be designed for a Venturi pressure drop of 25–30 in. w.g.

Carry-over of Droplets to the Stack

During some of the earlier tests, a ' rain ' of black droplets was experienced around the plant and a sheet of paper whisked through the plume was immediately bespattered with a mass of black spots. It is probable that this ' rain ' was caused by a sudden build-up of effluent liquor at the bottom of the cyclone. There was only just sufficient head between the cyclone base and drain level to balance the vacuum in the separator under normal conditions and either a sudden increase in Venturi or saturator water-rate (giving an increase in the separator vacuum) or a momentary blockage of the drain could cause the effluent level to build up past the inlet level of the gases from the Venturi. This would cause considerable pick-up of the effluent by these gases and the finer droplets would escape up the stack. Provision of a greater head between cyclone base and drain level in a full-scale plant should remove this difficulty.

Explosion Hazard

It is obvious from the gas analyses quoted in Tables VII and VIII that there are serious possibilities of explosion when diluent air is present in the proportions used in these tests. This was borne out by the flame seen in some experiments and by occasional bursts of pressure which were sufficient to raise the roof of the saturator. In one experiment (No. 12), a fairly strong explosion occurred within the ladle at the end of the blow, throwing out molten slag and metal. It may be relevant that the lanced metal in this test had reached a particularly low silicon content so that although the analytical values for fall in

Table IX

HEAT BALANCE OF GASES LEAVING HOOD

IN		OUT	
Source	**B.t.u./min**	**Source**	**B.t.u./min**
Heat of combustion of CO	84,500	Sensible heat absorbed by air	$4750 \times 0{\cdot}018\ (t-200)$
Radiation from ladle absorbed by gases	400		
Sensible heat of fume absorbed by air	$250 \times 0{\cdot}018\ (2000-t) = 4{\cdot}5\ (2000-t)$		
Total	$93{,}900-4{\cdot}5t$	Total	$81\ (t-200)$

Thus $93{,}900 - 4{\cdot}5t = 81t - 16{,}200$
$85{\cdot}5t = 110{,}100$
$t = 1290°$ F (700° C)
i.e. outlet temperature of gas from hood = 1290° F (700° C)

carbon content are not so great as on some other occasions, it is probable that serious decarburization would be commencing at this point.

The inflammability limits of carbon monoxide mixtures are very wide; a range from 11 to 78% is quoted[15] for mixtures with air at 400° C and in the higher temperatures prevailing at the metal surface, it will undoubtedly be wider still. For any commercial plant of this type there are, then, two possibilities:

(*a*) The hood is made completely air-tight to prevent air leakage into the system (at least until after the gases have been cooled past the explosion temperature).

(*b*) Enough air is drawn in, using a loose hood, to provide an air–carbon-monoxide mixture outside the explosion range at this high temperature. In this case, good mixing of the fume and inspirated air in all parts of the hood must be ensured to prevent the formation of pockets of explosive gas. This mixing will probably be ensured by using:

(i) A low hood, i.e. with the crown as close to the top of the ladle as possible (the lower limit would probably be fixed by excessive heating of the hood crown)
(ii) The use of vent pipes to give a turbulent pattern to the gas flow at points in the hood where gas pockets may occur.

In the light of this discussion, alternative designs for a final plant are presented below. The final choice will rest on a consideration of the safety, practical difficulties, and economics of the two designs.

Alternative Plant Designs

Plant 1—No Air Drawn into the Hood

Though we have no accurate measure of the total gas quantity given off from the ladle (nor its variability) it is probably of the order of 200 normal ft³/min, and will not exceed 250 normal ft³/min. It is advisable to provide a scrubber to handle 600 normal ft³/min of total gas, i.e. 800 ft³/min at the Venturi conditions (50° C and saturated)—the remaining gas to be supplied by a small air-bleed directly before the Venturi—for the following reasons.

The scrubber will only work efficiently when dealing with a constant throughput of gas, since efficiency depends on a high gas velocity in the throat. Near the end of the blow the fume quantity will drop off, so for operation both at the beginning and end of the blow (and for flexibility during the blow, where the fume quantity might fluctuate considerably) an air-bleed before the Venturi is necessary. This air-bleed will be situated between the saturator and Venturi, since at this point the gases will be at a sufficiently low temperature to exclude the possibility of explosion with any mixture of CO and air.

Plant 2—Enough Air Drawn into the Hood to Prevent Explosions

As stated for Plant 1 the total fume given off at the ladle can be taken as a maximum of 250 normal ft³/min. For this design it will be assumed that this fume is entirely composed of carbon monoxide. If 4750 normal ft³/min of air is introduced into the hood the maximum percentage of CO before reaction will be $(250 \times 100)/5000 = 5\%$. If thorough mixing of the gases is ensured there should be no danger of explosion.

The temperature of the mixed gases cannot be calculated accurately since values must be assumed for the following unknowns:

(i) The initial quantity of CO emitted from the ladle (before reaction).
(ii) The heat input to the air by convection as it passes between the ladle sides and the hood.
(iii) Fume temperature as it leaves the ladle.

The outlet temperature of the gas from the hood has been calculated making the following assumptions:

(i) Air temperature after passing between the ladle sides and the hood on entering the gas stream = 200° F (93° C).
(ii) Ladle temperature = 2550° F (1400° C).
(iii) Fume temperature on leaving the ladle = 2000° F (1100° C).
(iv) Initial fume composition—250 normal ft³/min of CO.
(v) All the CO reacts to CO_2 in the hood.

These assumptions are all conservative, i.e. the calculated outlet temperature of the gases from the hood will be higher than the actual temperature to be expected.

The heat of combustion of CO = 4340 B.t.u./lb; thus the heat of reaction of 250 normal ft³/min CO = 84,500 B.t.u. From consideration of the CO_2 present in the final gases radiation from the ladle absorbed by gases = 400 B.t.u./min.

The mean specific heat of gas and air = 0·018 B.t.u. (normal ft³ and ° F). If t° F is final temperature of the gases leaving the hood the heat balance is as shown in Table IX.

Diagrammatic layouts of these plants showing the approximate sizes of the vessels are shown in Figs. 5 and 6.

Treatment of the Effluent Liquor

There are two ways of treating the effluent liquor from both saturator and scrubber:

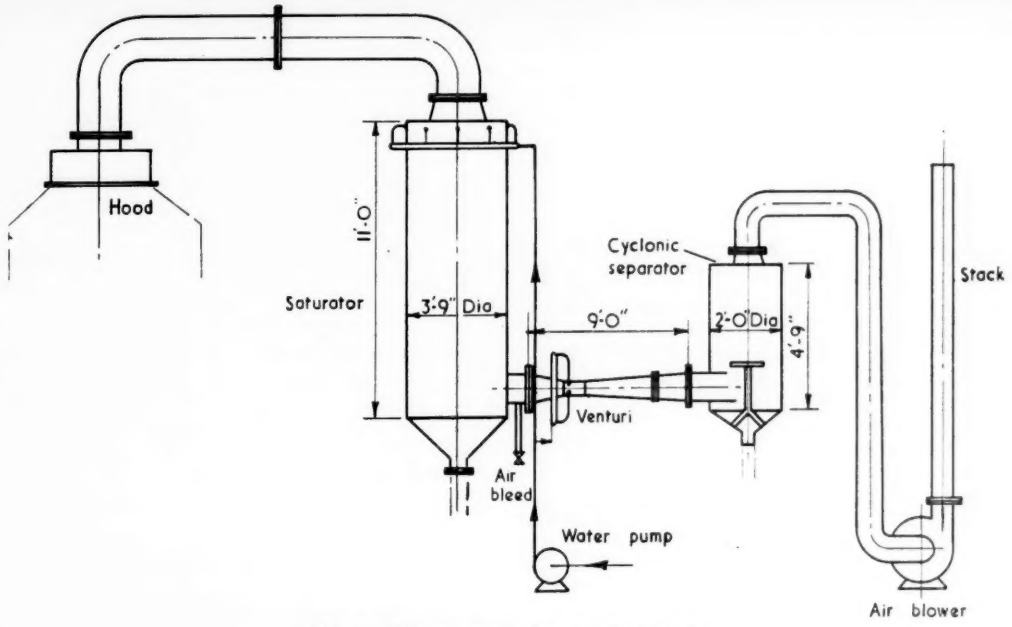

Fig. 5—Diagrammatic layout of Plant 1

(*a*) By means of a mechanical thickener, followed by filtration of the sludge if necessary
(*b*) By means of settling pits.

The possibility of using a mechanical thickener is being investigated and for the purposes of the assessment of the cost per ton the design and cost of settling pits are considered here. For both plants the settling pits will take the form of concrete tanks sunk into the ground, with three or more compartments in each. A settling time of 30 min has been allowed in both cases, on the basis that any material too fine to settle within 30 min is not likely to

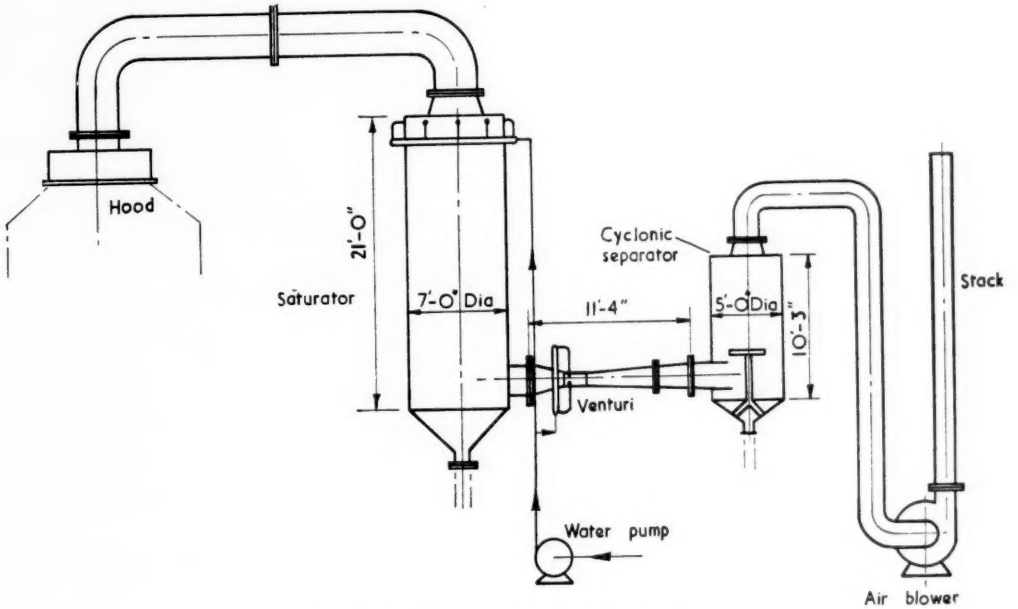

Fig. 6—Diagrammatic layout of Plant 2

block the jets in either the scrubber or the Venturi.

In order to facilitate sludge removal it may be necessary to duplicate these pits but for this cost estimate it will be assumed that the sludge can be pumped from the pit bottom without using a duplicate pit. The problem of sludge disposal remains to be dealt with. The total solids are expected to amount to 1½ tons/day and it is possible that the sludge may be suitable for treatment in the sinter plant.

ASSESSMENT OF DESIGN RECOMMENDATIONS

Practical Considerations—Hood Design

The only part of the plant in which the two designs differ basically is in the design of the hood. In outline both hoods will be similar (and their cost roughly equal). They will be brick-lined, with crowns as low as is consistent with support of this arched brickwork. The hood for Plant 2, where air is drawn in, will have air vents placed in the top of the hood wherever pockets of gas are likely to accumulate to give the necessary turbulent mixing.

It is felt that, with Plant 1, an air-tight seal may best be maintained by resting the hood in a sand trap round the lip of the ladle. This will present several practical difficulties, such as retaining the sand in its trap when the ladle is tipped up for pouring after the hood has been removed, and retaining an air-tight seal at the pouring spout while lancing is in progress (the final seal round the spout would probably have to be made with fireclay). While in theory neither of these difficulties is prohibitive, in practice more labour may be required and there may be some practical difficulty in retaining a complete seal. Thus the practical difficulties of the hood design must be given equal weight with the economic considerations below in finally deciding which design to adopt.

In either case, it is suggested that the most practical method of placing the hood on the ladle and removing it may be by means of a crane, i.e. in the same fashion as in the tests carried out.

Economic Assessment

In a paper such as this it is not intended to give an economic assessment to cover all possible applications. This assessment will deal specifically with the application of the two designs discussed above to dealing with a 120-ton cast, in four 30-ton batches every 2 h. The operating cost in pence per ton given for each design will be conservative and will be reduced if more than 30 tons can be treated in one ladle.

Capital Cost

The capital cost given includes for the supply and erection on prepared foundations of the items shown on Figs. 5 and 6 and will, in each case, comprise essentially the following items: brick-lined hood; brick-lined saturator; Venturi scrubber in stainless steel; cyclonic separator, gunnited with cement; fan with cast-iron body and stainless-steel impellor, motor, and starter; water pump, motor, and starter; ducting; water piping; instruments.

The cost of foundations is taken as 5% of the plant cost.

In arriving at the cost of settling pits normal conditions for excavation are assumed and the prices given are for the installed cost. Sludge disposal equipment is not included.

For the scrubbing plant, including the hood, depreciation and maintenance are taken as 20%. This may be considered as 7½% for maintenance and 12½% for depreciation.

Maintenance costs for the scrubber are normally low but the 7½% should allow for adequate maintenance of the brick-lined hood and ducting.

Depreciation on the settling pits and foundations is taken at 5%.

Power Consumption

This is assessed on the basis of a 29-in. w.g. pressure drop across the Venturi, with an overall pressure drop of 32 in. w.g. and it is assumed that the scrubbing system will operate for 30 min per blow. Duration of the blow is taken to be 20 min. The power cost is taken as 1·0 pence/kWh.

Water Consumption

Water losses are taken to be the loss due to evaporation in the scrubber and saturator plus 1% loss in the sludge from the settling unit. The water cost is taken as 15 pence per 1000 gal.

Labour Costs—The operation of the scrubber will be very simple, and it is believed that within the range considered here, the extra labour required (over that chargeable to desiliconization) would be only one man, irrespective of the volume of entrained air and of the scale of operation. Thus the labour cost will always be the wages of one man (formally taken at 5*s.* per hour) for the furnace cast-to-cast time (2 h) charged against the weight of one complete cast (120 tons).

Cost Analysis—The following schedule has been considered for each of the two hood designs:

Four plants, used simultaneously for four 30-ton batches, each plant having an average blow-to-blow time of 120 min, treating overall 120 tons of metal in 120 min, or 10,000 tons per week. Oxygen lancing time 20 min and scrubbing time 30 min per ladle.

Plant 1—Fume treated—One scrubber for each ladle, each scrubber treating 530 normal ft³/min.

Capital cost (basis—four scrubbers)

Hoods, scrubbers, etc.	£23,500
Foundations (estimated)	1,175
Settling pits	500
Total	£25,175

	Cost per unit	Units per blow	Cost (pence/ton)
Depreciation and maintenance on hoods, scrubbers, etc. at 20% of capital cost			**2·260**
Depreciation on settling pits and foundations at 5% of capital cost			**0·040**
Power	**1·000**	**8·6 kWh**	**0·077**
Water	**0·015**	**600 gal**	**0·075**
Labour	**60**	**2**	**1·000**
Total			**3·452**

Table X

UTILIZATION OF OXYGEN IN METALLOID REMOVAL

	1	2	3	4	5	6	7	8
Date	9.12.55	12.12.55	12.12.55	13.12.55	13.12.55	14.12.55	14.12.55	15.12.55
Furnace no.	2	1	2	2	1	1	2	2
Time of injection* (min)	20	15	18	20	19	18	20	20
Weight of metal (tons)	30·2	24·9	34·5	32·0	32·6	29·5	35·45	32·0
%Si Initial value	0·78	0·31	0·62	0·89	0·55	0·33	0·50	0·53
Decrease	0·36	0·20	0·29	0·52	0·42	0·19	0·29	0·22
Equivalent oxygen (ft³)	3338	1529	3072	5108	4203	1721	3156	2161
%Mn Initial value	1·14	0·70	1·10	1·25	1·05	0·82	1·02	1·17
Decrease	0·36	0·32	0·32	0·43	0·46	0·38	0·37	0·33
Equivalent oxygen (ft³)	848	622	861	1073	1170	874	1023	824
%C Initial value	3·98	3·59	3·61	4·08	4·03	4·03	4·07	4·13
Decrease	−0·11	0·08	0·05	0·05	0·05	0·10	0·22	0·08
Equivalent oxygen (ft³)	−1193	715	619	574	585	1059	2800	919
%S Initial value	0·032	0·099	0·069	0·060	0·050	0·079	0·064	0·024
INCREASE	0·009	0·001	0·016	0·010	0·016	−0·001	0·013	0·004
Equivalent oxygen (ft³)	−73	−7	−149	−86	−139	8	−124	−34
%P Initial value	1·47	0·73	1·22	1·20	0·79	0·72	1·27	1·46
Decrease	0·01	0·05	−0·11	−0·10	0·00	0·01	0·04	0·02
Equivalent oxygen (ft³)	105	433	−1321	−1114	0	103	493	223
OXYGEN INJECTED (ft³)*	7900	5000	8000	8000	7200	7200	8600	5100
EFFICIENCY								
based on Si alone (%)	42	31	38	64	58	24	37	42
based on Si + Mn (%)	53	43	49	77	75	36	49	59
based on complete analysis (%)	38	66	39	70	81	52	85	80

	9	10	11	12	13	14	15	16
Date	16.12.55	16.12.55	17.12.55	17.12.55	4.1.56	4.1.56	5.1.56	5.1.56
Furnace no.	2	2	1	2	2	1	2	1
Time of injection* (min)	17	18	19	19	20	20	20	20
Weight of metal (tons)	29·85	33·55	37·5	30·9	28·15	29·45	29·45	39·4
%Si Initial value	0·42	0·37	0·67	0·25	1·06	0·76	0·96	0·75
Decrease	0·11	0·20	0·25	0·16	0·50	0·43	0·26	0·28
Equivalent oxygen (ft³)	1008	2060	2878	1518	4321	3888	2351	3387
%Mn Initial value	1·10	1·02	1·10	0·91	1·55	0·86	1·27	0·86
Decrease	0·19	0·33	0·18	0·42	0·37	0·32	0·18	0·19
Equivalent oxygen (ft³)	442	864	527	1012	812	735	413	584
%C Initial value	4·15	4·08	5·15	3·89	4·08	3·84	3·88	3·90
Decrease	0·09	0·06	0·19	0·11	0·10	0·23	0·03	0·11
Equivalent oxygen (ft³)	964	723	2558	1220	1011	2432	317	1556
%S Initial value	0·029	0·035	0·046	0·083	0·027	0·070	0·038	0·088
INCREASE	0·003	−0·007	0·006	0·035	0·005	0·002	0·019	0·004
Equivalent oxygen (ft³)	−23	63	−60	−291	−38	−16	−151	−42
%P Initial value	1·49	1·50	0·79	1·43	1·24	0·75	0·26	0·83
Decrease	0·01	0·04	0·00	0·04	0·00	−0·03	0·02	0·01
Equivalent oxygen (ft³)	104	467	000	430	000	−307	205	137
OXYGEN INJECTED (ft³)*	5500	5300	5900	6300	7260	6560	6960	6740
EFFICIENCY								
based on Si alone (%)	18	39	49	24	60	59	34	50
based on Si + Mn (%)	26	56	58	40	71	71	40	59
based on complete analysis (%)	45	79	100	62	84	100	45	84

* On some occasions, oxygen was wasted during penetration of the skull. The time involved has been subtracted from the total time of oxygen flow, and the volume adjusted in proportion

block the jets in either the scrubber or the Venturi.

In order to facilitate sludge removal it may be necessary to duplicate these pits but for this cost estimate it will be assumed that the sludge can be pumped from the pit bottom without using a duplicate pit. The problem of sludge disposal remains to be dealt with. The total solids are expected to amount to 1½ tons/day and it is possible that the sludge may be suitable for treatment in the sinter plant.

ASSESSMENT OF DESIGN RECOMMENDATIONS

Practical Considerations—Hood Design

The only part of the plant in which the two designs differ basically is in the design of the hood. In outline both hoods will be similar (and their cost roughly equal). They will be brick-lined, with crowns as low as is consistent with support of this arched brickwork. The hood for Plant 2, where air is drawn in, will have air vents placed in the top of the hood wherever pockets of gas are likely to accumulate to give the necessary turbulent mixing.

It is felt that, with Plant 1, an air-tight seal may best be maintained by resting the hood in a sand trap round the lip of the ladle. This will present several practical difficulties, such as retaining the sand in its trap when the ladle is tipped up for pouring after the hood has been removed, and retaining an air-tight seal at the pouring spout while lancing is in progress (the final seal round the spout would probably have to be made with fireclay). While in theory neither of these difficulties is prohibitive, in practice more labour may be required and there may be some practical difficulty in retaining a complete seal. Thus the practical difficulties of the hood design must be given equal weight with the economic considerations below in finally deciding which design to adopt.

In either case, it is suggested that the most practical method of placing the hood on the ladle and removing it may be by means of a crane, i.e. in the same fashion as in the tests carried out.

Economic Assessment

In a paper such as this it is not intended to give an economic assessment to cover all possible applications. This assessment will deal specifically with the application of the two designs discussed above to dealing with a 120-ton cast, in four 30-ton batches every 2 h. The operating cost in pence per ton given for each design will be conservative and will be reduced if more than 30 tons can be treated in one ladle.

Capital Cost

The capital cost given includes for the supply and erection on prepared foundations of the items shown on Figs. 5 and 6 and will, in each case, comprise essentially the following items: brick-lined hood; brick-lined saturator; Venturi scrubber in stainless steel; cyclonic separator, gunnited with cement; fan with cast-iron body and stainless-steel impellor, motor, and starter; water pump, motor, and starter; ducting; water piping; instruments.

The cost of foundations is taken as 5% of the plant cost.

In arriving at the cost of settling pits normal conditions for excavation are assumed and the prices given are for the installed cost. Sludge disposal equipment is not included.

For the scrubbing plant, including the hood, depreciation and maintenance are taken as 20%. This may be considered as 7½% for maintenance and 12½% for depreciation.

Maintenance costs for the scrubber are normally low but the 7½% should allow for adequate maintenance of the brick-lined hood and ducting.

Depreciation on the settling pits and foundations is taken at 5%.

Power Consumption

This is assessed on the basis of a 29-in. w.g. pressure drop across the Venturi, with an overall pressure drop of 32 in. w.g. and it is assumed that the scrubbing system will operate for 30 min per blow. Duration of the blow is taken to be 20 min. The power cost is taken as 1·0 pence/kWh.

Water Consumption

Water losses are taken to be the loss due to evaporation in the scrubber and saturator plus 1% loss in the sludge from the settling unit. The water cost is taken as 15 pence per 1000 gal.

Labour Costs—The operation of the scrubber will be very simple, and it is believed that within the range considered here, the extra labour required (over that chargeable to desiliconization) would be only one man, irrespective of the volume of entrained air and of the scale of operation. Thus the labour cost will always be the wages of one man (formally taken at 5*s*. per hour) for the furnace cast-to-cast time (2 h) charged against the weight of one complete cast (120 tons).

Cost Analysis—The following schedule has been considered for each of the two hood designs:

Four plants, used simultaneously for four 30-ton batches, each plant having an average blow-to-blow time of 120 min, treating overall 120 tons of metal in 120 min, or 10,000 tons per week. Oxygen lancing time 20 min and scrubbing time 30 min per ladle.

Plant 1—Fume treated—One scrubber for each ladle, each scrubber treating 530 normal ft³/min.

Capital cost (basis—four scrubbers)

Hoods, scrubbers, etc.	£23,500
Foundations (estimated)	1,175
Settling pits	500
Total	£25,175

	Cost per unit	Units per blow	Cost (pence/ton)
Depreciation and maintenance on hoods, scrubbers, etc. at 20% of capital cost			2·260
Depreciation on settling pits and foundations at 5% of capital cost			0·040
Power	1·000	8·6 kWh	0·077
Water	0·015	600 gal	0·075
Labour	60	2	1·000
Total			3·452

Table X

UTILIZATION OF OXYGEN IN METALLOID REMOVAL

	1	2	3	4	5	6	7	8
Date	9.12.55	12.12.55	12.12.55	13.12.55	13.12.55	14.12.55	14.12.55	15.12.55
Furnace no.	2	1	2	2	1	1	2	2
Time of injection* (min)	20	15	18	20	19	18	20	20
Weight of metal (tons)	30·2	24·9	34·5	32·0	32·6	29·5	35·45	32·0
%Si Initial value	0·78	0·31	0·62	0·89	0·55	0·33	0·50	0·53
Decrease	0·36	0·20	0·29	0·52	0·42	0·19	0·29	0·22
Equivalent oxygen (ft³)	3338	1529	3072	5108	4203	1721	3156	2161
%Mn Initial value	1·14	0·70	1·10	1·25	1·05	0·82	1·02	1·17
Decrease	0·36	0·32	0·32	0·43	0·46	0·38	0·37	0·33
Equivalent oxygen (ft³)	848	622	861	1073	1170	874	1023	824
%C Initial value	3·98	3·59	3·61	4·08	4·03	4·03	4·07	4·13
Decrease	−0·11	0·08	0·05	0·05	0·05	0·10	0·22	0·08
Equivalent oxygen (ft³)	−1193	715	619	574	585	1059	2800	919
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INCREASE	0·009	0·001	0·016	0·010	0·016	−0·001	0·013	0·004
Equivalent oxygen (ft³)	−73	−7	−149	−86	−139	8	−124	−34
%P Initial value	1·47	0·73	1·22	1·20	0·79	0·72	1·27	1·46
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Equivalent oxygen (ft³)	105	433	−1321	−1114	0	103	493	223
OXYGEN INJECTED (ft³)*	7900	5000	8000	8000	7200	7200	8600	5100
EFFICIENCY								
based on Si alone (%)	42	31	38	64	58	24	37	42
based on Si + Mn (%)	53	43	49	77	75	36	49	59
based on complete analysis (%)	38	66	39	70	81	52	85	80

	9	10	11	12	13	14	15	16
Date	16.12.55	16.12.55	17.12.55	17.12.55	4.1.56	4.1.56	5.1.56	5.1.56
Furnace no.	2	2	1	2	2	1	2	1
Time of injection* (min)	17	18	19	19	20	20	20	20
Weight of metal (tons)	29·85	33·55	37·5	30·9	28·15	29·45	29·45	39·4
%Si Initial value	0·42	0·37	0·67	0·25	1·06	0·76	0·96	0·75
Decrease	0·11	0·20	0·25	0·16	0·50	0·43	0·26	0·28
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* On some occasions, oxygen was wasted during penetration of the skull. The time involved has been subtracted from the total time of oxygen flow, and the volume adjusted in proportion

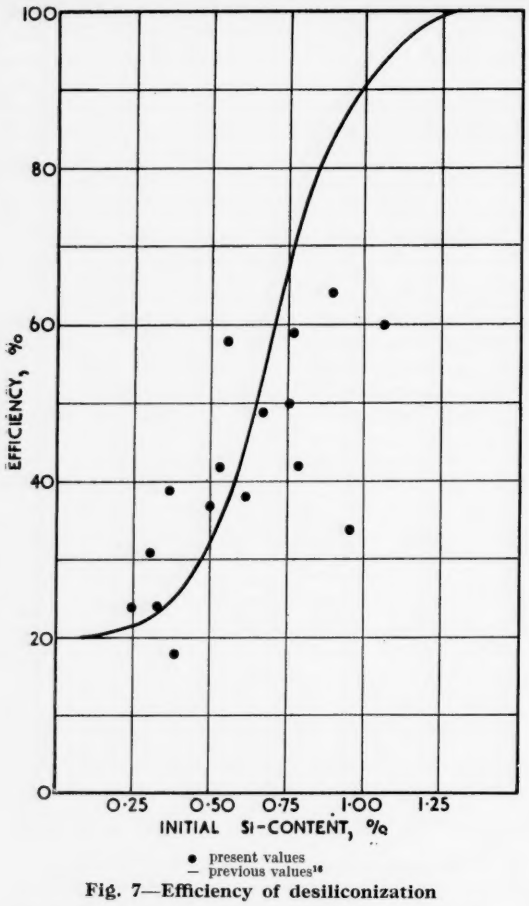

Fig. 7—Efficiency of desiliconization

Plant 2—Fume treated—One scrubber for each ladle, each scrubber treating 5000 normal ft³/min.

Capital cost (basis—four scrubbers)

Hoods, scrubbers, etc.	£46,500
Foundations (estimated)	2,325
Settling pits	1,400
Total	£50,225

	Cost per unit	Units per blow	Cost (pence/ton)
Depreciation and maintenance on hoods, scrubbers, etc. at 20% of capital cost			**4·460**
Depreciation on settling pits and foundations at 5% of capital cost			**0·090**
Power	**1·000**		**0·643**
Water	**0·015**		**0·450**
Labour	**60**	**2**	**1·000**
Total			**6·643**

CONCLUSIONS

The Pease-Anthony scrubber, as used in these tests, proved capable of cleaning submicron iron oxide fume to concentrations of approximately 0·1 gr/ft³, giving a colourless stack-gas after the evaporation of water vapour. It is probable that the outlet dust concentration can be still further reduced by increasing the pressure drop across the Venturi from 15 to 30 in. w.g.

The fume particles were predominantly oxides of iron (85–95%) with small quantities of metalloid oxides.

Indications have been obtained that both the weight and volume of the fume are increased with increasing volumes of air drawn into the hood.

Under the circumstances described, 70–100 lb of fume was emitted in about 16,000 normal ft³ of gas from 30 tons of metal in 20 min.

The actual gas emitted from the ladle appears to be mainly carbon monoxide, formed by a small degree of decarburization. If this is allowed to mix with relatively small quantities of air, or if stagnant pockets of carbon monoxide and air are formed, there is an explosion hazard.

The spray tower used removed up to 60% of the total fume, but experience in other fields indicates that this is the maximum efficiency to be expected from this type of scrubber. It is also probable that only the larger size of particle was removed in the saturator.

Two designs for a full-scale plant have been put forward:

(*a*) A plant to scrub a total of 530 normal ft³/min gas, made up of the fume from an air-tight hood and an air-bleed in the saturator. This scheme will give the lowest running cost but its safety depends on maintaining an air-tight seal between hood and ladle. Under these conditions a conservative estimate of the cleaning cost is 3·45 pence/ton.

(*b*) A plant to scrub a total of 5000 normal ft³/min, air being drawn into the hood through a loose joint between hood and ladle. With a low-crowned hood and adequate air-vents to prevent the formation of pockets of explosive gas, this should be a completely safe arrangement and quite simple both to operate and maintain. The gases should leave the hood at less than 1300° F, thus relieving the load on the precooler.

The estimated scrubbing cost of 6·64 pence/ton would be greater than Case (*a*), but considerably less than that quoted for other commercial installations of this type where considerably more air is drawn into the hood.

Treatment of the effluent from both saturator and scrubber can be accomplished using either a thickener or settling pits. Water would be recirculated to both scrubber and saturator. It may be possible to dispose of the sludge by charging it to the sintering plant.

Acknowledgments

The authors wish to thank the managements of Dorman Long (Steel) Ltd., The Power-Gas Corporation Ltd., and the British Oxygen Co., Ltd., for their permission to publish this paper, and to the many colleagues who co-operated in this work, particularly Mr. E. Eason, works manager, and the staff of the Blast Furnace Department, Redcar Works, Dorman Long (Steel) Ltd., and Mr. I. W. Shedden, Power-Gas Corporation Ltd.

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APPENDIX

Efficiency of Metalloid Removal

The appropriate metal analyses are recorded in Table X with the amounts of oxygen injected and utilized.

Some slag samples were taken after blowing the metal with oxygen, but owing to the heterogeneous nature of the slag, particularly undissolved lumps of lime, it was impossible to obtain a true average slag analysis. Some blast-furnace slag was carried over into the ladle as can be seen from the high alumina and magnesia contents of the spot samples, the analyses of which are shown in Table XI.

Silicon and manganese were reduced by roughly similar amounts and carbon was also reduced after treating with oxygen. Sulphur, however, tended to increase. It is thought that the sulphur increase was due to reversion of sulphur from the blast-furnace slag, of high sulphur content (about 1·7%) carried over into the ladle.

Table XI

ANALYSES OF SPOT SAMPLES OF SLAG TAKEN AFTER BLOWING METAL WITH OXYGEN, %

Test No.	2	4	5
CaO	21·5	30·1	25·4
MgO	5·3	4·2	4·2
SiO_2	39·6	37·6	45·2
P_2O_5	2·06	0·73	0·59
FeO	9·55	4·64	5·16
Al_2O_3	10·45	9·78	8·86
MnO	10·3	12·4	9·8
S	0·57	0·45	0·51

The efficiency of utilization of oxygen has been calculated (Table XI) by three distinct methods:

(*a*) Considering only the fall in Si
(*b*) Considering only the fall in Si and Mn
(*c*) Also including the changes, positive or negative, in the other metalloids.

By each method, the efficiencies obtained are extremely variable and some are very low. It is well known that the efficiency of desiliconization is markedly dependent upon the initial silicon content, and in Fig. 7 the present values have been plotted, for comparison, on the same graph as a line calculated from previous data.[16]

It will be seen that the silicon efficiency is, indeed, markedly dependent upon the initial Si ($r = 0·81$); $p = 0·001$) and that below about 0·9% the present data agree well with the previous curve. There are two misfits at higher levels, but the worst of these was known to be a case of inadequate penetration of the lance.

Superficial examination of the data has not revealed any similar patterns in the efficiencies of removal of the other metalloids; falls in analyses appear to be random and may depend on variations in handling of the lance and difficulties in obtaining representative samples for analysis.

The Nature of Mechanically Polished Metal Surfaces

DEFORMATION PRODUCED DURING ABRASION OF 18/8 TYPE AUSTENITIC STEEL

By L. E. Samuels, B.Met.E., M.Sc., A.I.M., and G. R. Wallwork, A.S.T.C., B.Sc., A.I.M.

SYNOPSIS

The structure of the deformed surface layer produced during the abrasion of an 18/8 austenitic steel has been investigated by a metallographic taper-sectioning technique. The depth of the layer produced by various methods of abrasion used in metallographic practice has been investigated systematically and the optimum conditions of abrasion established. The requirements of mechanical methods of polishing necessary for the production of surfaces free from gross deformation are considered. The results are in good agreement with those of an earlier investigation using specimens of 70/30 brass. 1344

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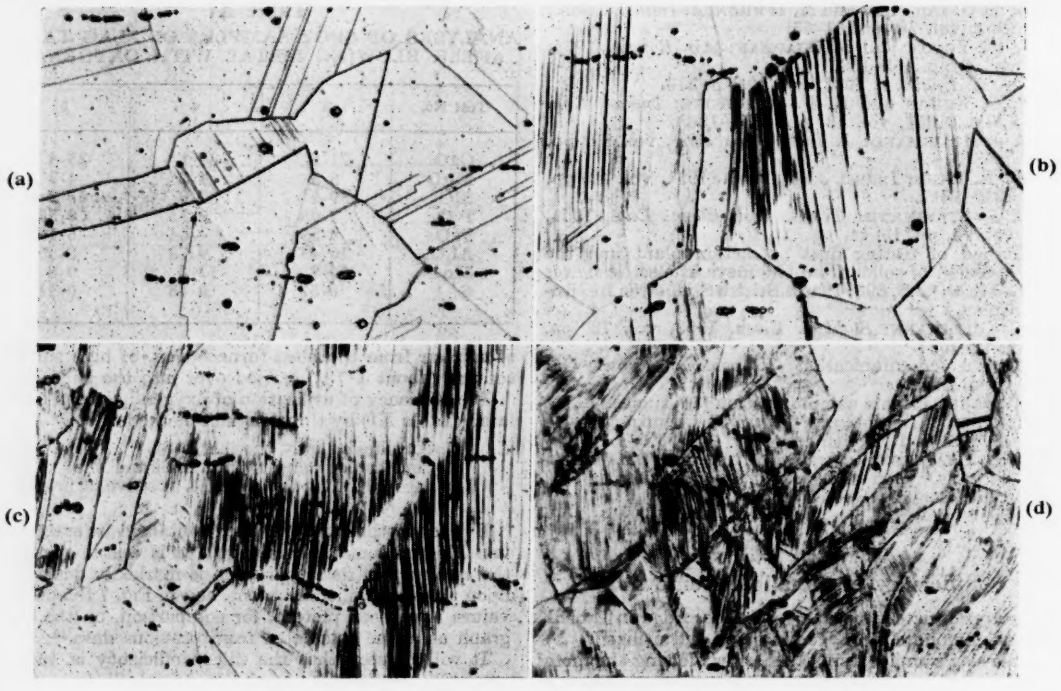
ONE OF THE AUTHORS has previously reported[1] an investigation using metallographic taper-sectioning methods into the origin of the gross deformation sometimes found on polished surfaces of 70/30 brass, a material chosen for investigation because prior deformation can be detected by metallographic methods with very high sensitivity.[2] This work has now been extended to a metastable austenitic steel because of the ease this alloy also affords in detecting deformation effects, and these results are reported in the present paper.



(*a*) 1% compression (*b*) 7·5% compression (*c*) 20% compression (*d*) 30% compression

Fig. 1—Sections of uniformly compressed specimens of 18/8-type austenitic steel. Compression direction horizontal. Etched electrolytically in oxalic acid solution. × 250

EXPERIMENTAL METHODS

Material

The experiments were carried out on a 0·5-in. dia. hot-rolled, low-carbon 18/8 Ni–Cr steel supplied by the Commonwealth Steel Co., Ltd., with the following composition in wt-%:

Carbon	0·06	Sulphur	0·020
Nitrogen	0·039	Nickel	10·5
Silicon	0·55	Chromium	19·0
Manganese	1·22	Copper	0·07
Phosphorus	0·033	Molybdenum	0·09

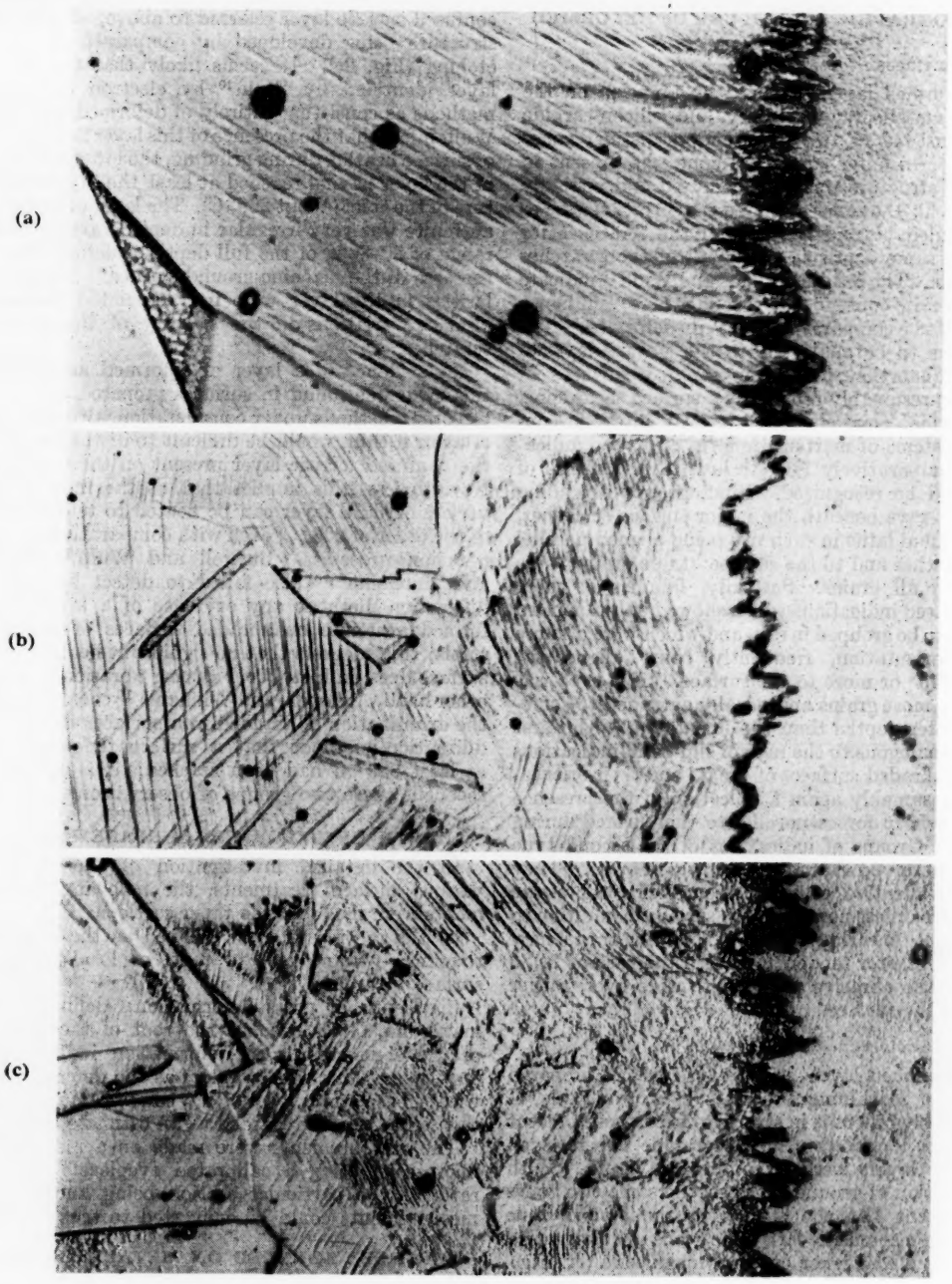
The bar was cut into discs which were austenitized at 1050° C for 1 h and water quenched; the hardness was then D.P.N.130. After heavy pickling, the discs were mounted in a phenol formaldehyde plastic, and a test surface prepared by metallographic polishing by a mechanical method[3] which is known to produce a surface which is completely free from deformation artifacts when etched.[4]

Abrasion of Test Surfaces and Method of Examination

The method of abrading the test specimens at arbitrarily chosen stages in the wear life of an abrasive paper (defined by the number of abrasion strokes carried out on a confined track) has been described in detail previously,[1] as has been the method of taper sectioning which enables the taper ratio of the final section to be determined with accuracy.[5] The final sections were polished mechanically[3] and were then etched electrolytically in a 10% oxalic acid solution. The abrasion processes investigated were: water-proofed silicon-carbide papers lubricated with flowing water, emery papers lubricated with kerosene, and a cast alumina-wax lap.[3] The investigation was also extended to cover a number of representative 'machining' processes of the type used in metallographic practice to prepare a preliminary flat surface; details of the processes investigated are given in Table II.

Sensitivity of Metallographic Method of Detecting Deformation

Deformation of austenitic 18/8 Ni–Cr steels at room temperature causes transformation to martensitic α_2-ferrite, the transformation occurring in plates or laths along the slip planes; the plates of α_2-ferrite are detectable as metallographic indications of deformation after etching by any of the standard methods for the material.[6] The characteristics of the transformation have been investigated recently by Cina,[7, 8] and by Fiedler, Averbach, and Cohen[9]; this work has shown that the volume of ferrite formed is related quantitatively to the amount of cold work, the exact relationship depending upon the method and temperature of deformation and upon the composition of the alloy. Therefore, in order that some attempt might be made to interpret the present results in at least a semi-quantitative manner, it was necessary to investigate the metallographic transformation characteristics of the material to be used when deformed under conditions approaching as closely as possible those existing during abrasion.



(*a*) Abraded on 220-grade silicon carbide paper. Taper ratio: 10·1. × 1000 (*b*) Abraded on 150-grade Aloxite cloth. Taper ratio: 13·3. × 1000
(*c*) Machine-ground surface. Taper ratio: 10·7. × 500

Fig. 2—Taper sections of abraded surfaces of 18/8-type austenitic steel. Etched electrolytically in oxalic acid solution

The best that can be done is to investigate specimens deformed by rapid compression. In such specimens, martensitic laths were first detected after about 1% compression (Fig. 1*a*), and this value will be accepted as the threshold sensitivity of the method of detecting deformation. In keeping with earlier published work,[6–9] both the number of laths in individual grains and the number of grains containing indications increased with increasing compression; Figs. 1*a–d* are representative.

METALLOGRAPHIC STRUCTURE OF DEFORMED SURFACE LAYERS

Abraded Surfaces

The deformed layer produced by abrasion on the standard metallographic emery and silicon-carbide papers consisted of two more or less distinct zones (Fig. 2*a*). An outer superficial zone was present in which the structure was very confused and virtually unresolvable; the zone contoured the surface scratches and extended beyond the root of the scratches for about the same depth as the depth of the scratches themselves. The results of Cina[7] and Wulff[10] indicate that the ferrite content of this zone is high, and hence that it must be comparatively heavily deformed. The zone seems to be analogous to the surface layer of severest distortion found on abraded surfaces of brass[1]; it presumably represents a surface shear zone.

The surface zone changed abruptly into one containing systems of martensitic laths of a type indicative of comparatively low strains. Two families of laths could be recognized. First, groups extending in distinct rays beneath the major surface scratches, the individual laths in each ray being aligned parallel to one another and to the surface: these groups were present in all grains. Secondly, families of more widely spaced indications which showed only a general tendency to be grouped in rays and which were of more random orientation, frequently being aligned at angles of 45° or more to the surface. This type was present in most grains and usually extended to somewhat greater depths than the first group. The first group is analogous to the rays of slip-band indications found in abraded surfaces of brass,[1] and their orientation is presumably again a reflection of the presence of heavy shear forces parallel to the surface during cutting.[11] Groups of indications of the second type were not observed in abraded surfaces of brass. They may be indicative of the presence of compressive forces more or less normal to the surface in addition to the surface shearing forces. This, in turn, may indicate a greater tendency than in the case of 70/30 brass for the abrasive particles to slide over, rather than cut, the surface.

Machined Surfaces

The deformed layers present on surfaces prepared by all the machining processes listed in Table II were notably different in structure from those present on surfaces abraded on metallographic papers, even where the layers were of comparable depth. With the exception of ground surfaces, the same two zones were present but the strains in the second zone containing martensitic lath indications of deformation were of a much higher order of magnitude (cf. Figs. 2*a* and *b*); from a comparison with uniformly compressed specimens, it would appear that strains exceeding the equivalent of 20% compression extended for some depth (cf. the central areas of the field shown in Fig. 2*b* with Fig. 1*c*). Moreover, the laths were more randomly arranged and showed less of a tendency to be arranged in rays beneath the abrasion scratches.

In the case of ground surfaces, the surface layer of the deformed zone was of an entirely different structure; it was much more resistant to etching than the confused surface layer referred to above, an irregular structure being developed by comparatively heavy etching (Fig. 2*c*). It seems likely that this is the layer identified by Wulff[10] by electron diffraction methods as consisting entirely of deformed austenite. Wulff infers that the presence of this layer is indicative of surface heating during grinding, the lower boundary of the layer having reached at least the M_d temperature of the steel (about 200° C). The layer of deformed austenite was very irregular in depth, varying in the range of 20–80% of the full depth of deformation in the case of the machine-ground surface. The irregularities in the layer were not associated with any obvious variations in the severity of the grinding scratches.

No evidence of a layer of deformed austenite of this type was found in surfaces prepared by any of the other methods under consideration, although such a layer, if thin, would be difficult to distinguish from the confused ferritic layer present on these surfaces. Nevertheless, this implies that at the most only a very superficial layer can be heated to temperatures of the order of 200° C, even with comparatively coarse abrasion processes. Burwell and Wulff,[12] Wulff,[10] and Yamaguchi[13] also failed to detect by electron diffraction methods any evidence of a layer of deformed austenite on abraded surfaces of austenitic steels; this suggests that no significant heating of the surface does, in fact, occur during abrasion. On the other hand, Agarwala and Wilman[14–16] concluded from the examination of abraded iron surfaces by electron diffraction methods that a surface temperature of at least 900° C had been reached; it is difficult to reconcile these two groups of observations.

DEPTH OF DEFORMED SURFACE LAYERS

In the detailed investigation of the effects of various surface treatments, the following measurements were made on the taper sections:

(i) Depth of scratches: defined as the maximum roughness, from crest to root, of local groups of surface scratches.

(ii) Depth of gross deformation: defined as the maximum depth beneath the root of the scratches of the zone containing deformation indications of any type. This will be taken as the deformed layer with a base strain level of 1% compression, although this figure can be regarded as an estimate only.

The measurements were made on a metallurgical microscope using a calibrated eyepiece; the taper ratio of the particular section being known, these measurements could be converted to true depths.

SURFACES ABRADED ON METALLOGRAPHIC ABRASIVE PAPERS

Effect of Wear of Abrasive Paper

The trend of the results was very similar to that found for 70/30 brass specimens. The depth of both the abrasion scratches and the deformed layer at first decreased as the paper became worn, but the paper soon reached a more or less stable condition (Fig. 3), stability being reached earlier with finer grades of paper (cf. Figs. 3*a* and *b*). The general conclusion reached previously, namely, that it is desirable to use slightly worn paper but that there

Table I

DEPTH OF SCRATCHES AND LAYER OF GROSS DEFORMATION PRODUCED BY, AND THE ABRASION RATE OF, VARIOUS METALLOGRAPHIC ABRASION PROCESSES

Abrasion Method		Depth, μ		Abrasion Rate, μ/min
Type	Grade	Scratches	Deformation	
Silicon carbide paper	220	0·7	6·0	9–18
	400	0·5	2·5	5–10
	600	0·4	2·2	3–7
Emery paper	1/0	0·8	5·0	2·5–5
	2/0	0·8	4·0	2–5
	3/0	0·6	4·0	1·5–2
	4/0	0·6	4·0	0·3–0·5
Alumina abrasive-wax lap	(10–20)μ	0·1	1·5	1·5–1·7

is no advantage in using very well worn papers, is therefore confirmed.

Effect of Abrasion Pressure

Comparisons were made between specimens abraded at 'normal' (about 500 g/cm²) and 'light' (about 100 g/cm²) pressures, respectively. As before,[1] no significant differences were found in either the maximum depth of the abrasion scratches or the maximum depth of the surface deformation. An explanation for this was suggested in the earlier paper.[1]

Grade of Abrasive Paper

The results obtained with the various grades of paper investigated are summarized in Table I, the figures given for the depth of the abrasion scratches and the layer of gross deformation being values for stabilized paper. Comparative values for surfaces abraded on a (10–20)μ-grade cast alumina-wax lap are also given in the table. The significant features are :

(*a*) The depth of the gross deformation was usually between 5 and 10 times the depth of the abrasion scratches. (*b*) The three types of silicon-carbide paper investigated constituted a graded series in which the depth of the scratches and the deformed layer both decreased progressively. (*c*) The four emery papers investigated did not constitute such a well graded series as, and covered a much narrower range than, the silicon-carbide papers. For example, the 3/0 and 4/0 grades were very similar to one another, and neither was greatly different from the 2/0 grade. This was because the 3/0 and 4/0 grade gave erratic results, presumably because the paper packs with debris giving rise to effects similar to those observed when 70/30 brass was abraded on the 4/0-grade paper.[1] (*d*) The depth of the scratches and the deformed layer produced by the finest silicon-carbide papers were both slightly less than the corresponding values for the finest emery papers. (*e*) The depth of the scratches produced on the abrasive-wax lap was considerably less than, and the depth of deformation was somewhat less than, the corresponding values for the finest grade of silicon-carbide paper.

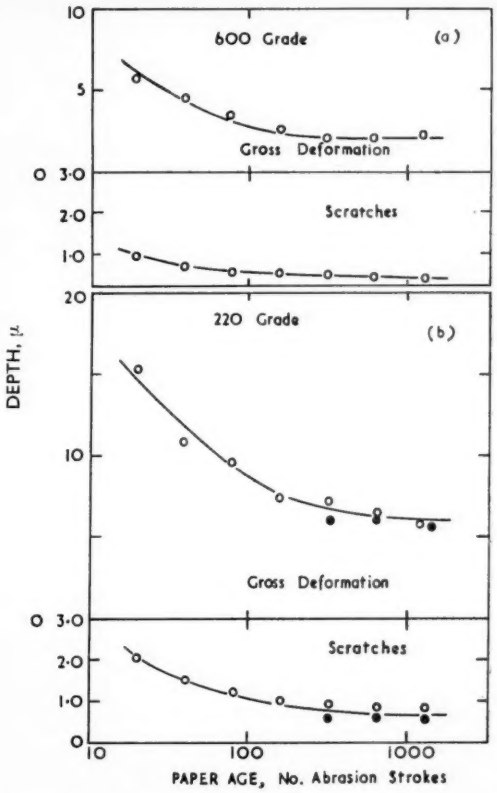


Fig. 3—Variation of depth of scratches and associated layer of gross deformation with increasing wear of abrasive paper. Silicon-carbide paper

Table II

DEPTH OF LAYER OF GROSS DEFORMATION PRODUCED BY REPRESENTATIVE PRELIMINARY MACHINING PROCESSES

Machining Process	Depth of Deformed Layer, μ
Lathe turned*	45
Machine surface ground†	35
Hand ground‡	43
Filed, 2nd cut§	46
Filed, smoothing§	34
Abraded on linisher belt, 100-mesh§	12
Abraded on Aloxite cloth, 150-mesh‖	12

* Faced at high speed with 0·001-in. cuts; unlubricated
† 0·0005-in. cuts with a 60-grit wheel; lubricated with commercial cutting compound
‡ Held lightly against a 60-grit side-faced wheel; unlubricated
§ Unlubricated
‖ Lubricated with kerosene

SURFACES PREPARED BY PRELIMINARY MACHINING PROCESSES

The present investigation was confined to a number of representative machining operations. The process chosen, together with measurements of the depth of the deformed layer produced, are listed in Table II.

In some instances these values can be compared approximately with those determined by Wulff,[10]

Table III

POLISHING RATES OF VARIOUS POLISHING PROCESSES, AND POLISHING TIMES REQUIRED FOR REMOVAL OF DEFORMED LAYER PRODUCED DURING ABRASION

Polishing Stage	Polishing Rate, μ/min	Polishing Time for Removal of Abrasion Deformation, min
1. Rough polishing		
Diamond, (4–8)μ	4·0–5·0	0·4
Alumina, 600 mesh	5·5–6·5	0·3
2. Fine polishing		
Alumina, (0–0·3)μ	1·0–2·0	1·5
Alumina, (0–0·1)μ	0·3–0·6	5·1
Magnesium oxide	<0·1	>15
3. Electrolytic polishing*	0·6	5·0

* Perchloric acid—acetic anhydride bath (Jacquet[17])

Note: This table refers to abrasion on the series 220-grade, 400-grade silicon-carbide papers, (10–20)μ -grade cast alumina-wax lap. The polishing times required after abrasion on the series 1/0-, 2/0-, 3/0-grades of emery paper would be about $2\frac{1}{2}$ times those listed.

and in all such cases the present determinations appear to be higher. A difference in this direction is to be expected because the sensitivity of the electron diffraction method used by Wulff for detecting deformation is likely to be appreciably less than that of the metallographic method used here. The depth measurements are known to be sensitive to this factor.[1]

REMOVAL OF THE DEFORMED LAYERS

A primary requirement of a metallographic preparation process is that the surface strains introduced during the preliminary abrasion should be reduced to a non-critical level in the final surface. This means that each stage of preparation must either completely remove the deformed layer produced by the preceding stage or at least reduce its depth to that being produced by the new stage.

Removal of Deformation during Successive Abrasion Stages

The abrasion rates for the hand abrasion of the austenitic-steel specimens at a 'normal' abrasion pressure were determined over the full wear life of each abrasive paper under investigation by the methods described previously.[1] As in the case of 70/30 brass specimens, the abrasion rate decreased approximately exponentially with paper wear. It follows that the papers are in an optimum condition for use in their middle life—the depth of deformation is unnecessarily great if they are used when too fresh and the abrasion rate is very low if they are used when too old. The abrasion rates in Table I are the range to be expected over an optimum life period selected on this basis. The important feature to note is that the abrasion rates of the silicon-carbide papers were generally considerably higher than those of the emery paper, particularly with finer grades; in fact, the abrasion rates of the 3/0- and 4/0-grade emery papers were considerably less than the polishing rates of rough-polishing process (cf. Tables I and III).

Consideration of the data given in Table I readily shows that a maximum treatment time of 0·5 min on any of the silicon-carbide papers used within their optimum life period should ensure that the depth of the deformed layer produced by the preceding paper of the series would be reduced to the depth of that being produced by the new stage. A treatment of this duration is well within practical limits. The same remarks apply to those emery-paper steps where there is a substantial difference between two successive grades of paper, and for the step from the 400-grade silicon-carbide paper to the wax lap. The general conclusion may be reached, therefore, that it is feasible to abrade a specimen by hand through either series of papers so that the depth of the gross deformation finally present is that characteristic of the particular stage at which abrasion ends.

Note, however, that the abrasion time required at each abrasion stage is by no means inconsequential; the classical recommendation that abrasion should be continued for as long again as it takes to remove the pre-existing scratches is quite inadequate. Moreover, it is obviously desirable that the abrasion rate at each stage should be made as high as possible by using heavy pressure and comparatively fresh paper.

Removal of Abrasion Deformation During Polishing

The polishing rates of mounted specimens of the steel were determined on pads charged with the abrasives listed in Table III. The tests were carried out on a mechanical wheel (300 rev/min) covered with a napped cloth, the specimen being rotated by hand in a direction contrary to that of the wheel at an applied pressure of about 200g/cm^2. The polishing pads have been grouped into: (*a*) rough-polishing processes using coarse abrasives, and (*b*) fine-polishing processes of the type used to obtain a final polish.

From a knowledge of these polishing rates, the maximum polishing time needed to remove the layer of gross deformation produced during abrasion can be estimated. Table III lists the times needed after abrasion under optimum conditions, namely, on the series 220-, 400-grades silicon-carbide papers and (10–20) μ-grade alumina-wax lap. The corresponding times after abrasion on the series 1/0-, 2/0-, 3/0-grades emery papers would be about $2\frac{1}{2}$ times those shown in this table. It can be concluded that the removal of the deformed layer produced by abrasion on the silicon-carbide paper series is well within practical limitations for both of the rough-polishing processes investigated; it is probably also possible after abrasion on an emery-paper series. The likelihood of removing the deformed layer would be much smaller, however, when polishing is confined to stages using fine abrasives, and may even be outside practical expectations. It is also doubtful whether the practice of alternate polishing and etching at one of these fine polishing stages would materially affect this situation. This supports the general conclusion reached previously[1] that a fundamental requirement of mechanical methods of polishing is that abrasion should be followed by a rough-polishing process with a high cutting rate which is designed specifically to remove the deformed layer produced during abrasion.

This process may then be followed by a stage (or stages) designed to produce a satisfactorily scratch-free surface.

For comparison, the polishing rate obtained in a perchloric-acid–acetic-anhydride electrolytic polishing bath (Jacquet[17]) is also shown in Table II. The time required to remove the layer of gross deformation produced by any of the abrasion methods considered here is substantial, but is within practical limits for a process which does not require continuous personal attention. Nevertheless, the principles discussed above still apply, and a surface adequately free from deformation will be obtained only if the electrolytic polishing treatment is made of sufficient duration.

Removal of Deformed Layer Produced during Preliminary Machining

It is surprising, in view of the conclusions reached in the preceding section, that investigators who have used rough-polishing stages of the type discussed have still found considerable difficulty in eliminating deformation artifacts in the final surface (for example, see Vilella[18] and Mayer, Rahrer, and Vilella[19]). Moreover, the artifacts shown in many of the micrographs published to illustrate this point are of much greater severity than would be expected from surface deformation produced on abrasive papers, as judged from taper-sections of the type shown in Fig. 2*d*. They are more of the type found in the intermediate layers of taper-sections of specimens prepared by preliminary machining processes (Fig. 2*b*). These considerations suggest the possibility that the deformation responsible for artifacts in finish-polished surfaces might, on some occasions, be remnant from the preliminary machining operations.

The first metallographic abrasion paper is the stage at which the machining deformation should be removed and probably is, in practice, the only stage at which its removal can be expected. Consideration of the data given in Tables I and II indicates that the situation could well arise where only a fraction of the machining deformation would be removed in a treatment of normal duration on the first metallographic abrasive paper. This draws attention to the importance of two features: first, the need to choose a preliminary machining procedure which results in the minimum depth of deformation, and secondly, the desirability of attaining the maximum possible cutting rate in the first metallographic abrasion stage. The present work has not been extensive enough to enable any firm recommendations to be made as to the most suitable machining procedures, although the trend is clear. It can be stated fairly definitely, however, how the maximum abrasion rate may be achieved at the first metallographic abrasion stage, namely, by using a coarse silicon-carbide paper in a comparatively fresh condition and with the maximum abrasion pressure. Even so, some care is likely to be necessary with the coarsest papers used normally to ensure complete removal of the machining deformation by hand abrasion. The first abrasion stage is therefore the one which might be used with most profit as a mechanized wheel, particularly where large numbers of specimens have to be handled.

DISCUSSION

The results of the present work are in good agreement with those of the earlier work on 70/30 brass.[1] In particular, it has been confirmed that the gross deformation frequently reported as being present in mechanically polished surfaces of metastable austenitic steels originates during the preliminary abrasion stages of preparation, and it has been shown that this deformation can, in fact, be reduced to an acceptable level (at least to a residual strain level equivalent to 1% compression) by suitable mechanical methods of polishing. The latter does not present any special difficulties but only requires that a preparation procedure be adopted which has been designed for this purpose instead of merely to produce an adequately scratch-free surface, as is the case for many classical mechanical polishing methods.

In addition, the present work has indicated that machining operations of the type frequently necessary for the preparation of a preliminary flat surface are a further possible source of the gross deformation found in polished surfaces. It follows that these preliminary operations must be chosen with care and that the first metallographic abrasion stage must be designed to remove the deformed layer so produced.

It was suggested when discussing the results of the earlier work that the depth of deformation produced by a particular abrasion process might be expected to be inversely proportional to the hardness of the specimen material; the deformed layers produced in 70/30 brass and in an austenitic stainless steel can now be compared approximately to obtain some check on this assumption. The ratio of the depths of the deformed layers with a base strain level of about 1% compression under similar conditions varied in individual cases from 3 to 6, whereas the inverse ratio of the hardnesses of the two materials is 2·9. In view of the difficulties in making this comparison, particularly in ascribing a definite base strain value to the respective deformed layers, the agreement between the two ratios may be as good as can be expected. However, the possibility that other factors may also be of importance in some instances still cannot be excluded.

Acknowledgments

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A Width Meter for Hot Steel Strip

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SYNOPSIS

A method has been evolved by means of which a width meter for hot-rolled strip could be built, obtaining its readings by electrically combining the indications from two optical units sensitive to the infra-red radiations from the strip, mounted several feet above the edges of the strip. An experimental model of such a unit has been built, which demonstrated that width could be read to $\pm \frac{1}{16}$ inch with a speed of response of 0·15 seconds. The outline of a complete instrument is described, and commercial instruments are now nearing completion using this principle. 1397

CONSIDERABLE ECONOMIES can be obtained in the production of hot steel strip if a method of continuously measuring its width is available. In the absence of such a method, strip must always be produced appreciably greater than the desired width, and the excess trimmed off afterwards, or the material may be sold overwidth. If a sufficiently accurate method for continuously monitoring the width is available, and is used as a guide in controlling the rolling process, the loss may be considerably reduced.

Although attempts have been made in the past to produce a satisfactory measuring system, none has been completely successful. One of the most recent is that described by Petersen.* When B.I.S.R.A. was consulted by the industry on this problem a method was evolved to provide the basis for a width measuring instrument which, it was believed, would prove sounder in principle and superior in performance, as well as being cheaper in initial cost and suitable for development by a British instrument firm.

The system consists basically of two units (the 'follower' units) each indicating the variation in position of a strip edge. These variations are summed algebraically by an electrical system to give the net variation in width, which, when added to the basic width given by the separation of the two units, gives the total width of the strip.

The feasibility of the system depended on the performance of these two 'follower' units, as the remainder of the instrument could be engineered by well-established practice in electrical servo and follower mechanisms. One such unit was produced by B.I.S.R.A. and tested in the laboratory on a model accurately simulating the strip edge. The performance of this unit exceeded the requirements. It was arranged that the development of the rest of the instrument should be undertaken by an instrument firm of suitable experience. Two installations are now approaching completion.

The following report gives a general outline of the scheme, and describes in detail the 'follower' unit developed by B.I.S.R.A.

GENERAL CONSIDERATIONS

The strip passing through a mill, as constrained by the guides, has a freedom of lateral movement amounting to several inches, so any method of width measurement applied to the mill as it stands must be such that the simultaneous movements of the strip edges caused by bodily movements of the strip cancel out and do not affect the reading of width.

The strip is normally at a temperature of about 900° C. It therefore radiates light, mainly in the red end of the spectrum, and a considerable amount of infra-red radiation. Lead sulphide photoconductive cells were used to give an indication of the position of a strip edge from the radiations it emitted. The cells used are extremely sensitive to infra-red radiation, and this sensitivity can be utilized to give a very accurate measure of edge position from a unit placed a considerable distance away. This in turn reduces the need for protection from heat and dust rising from the strip.

The schematic diagram of Fig. 1*a* shows the principle of the complete system. The two follower units are sited vertically above the edges of the strip at opposite sides. In each, a lens with its axis vertical forms an optical image, using infra-red light, of the part of the strip (including the edge) immediately below the unit. The movements of the strip edge are therefore reproduced, on a reduced scale, by its image in the follower unit. A moving shutter with a straight edge in the image plane is made to follow the movements of the image, so as to obstruct all light except that from a narrow element adjacent to

* G. R. PETERSEN, *Steel*, 1952, vol. 131, Sept. 29, pp. 94–97.

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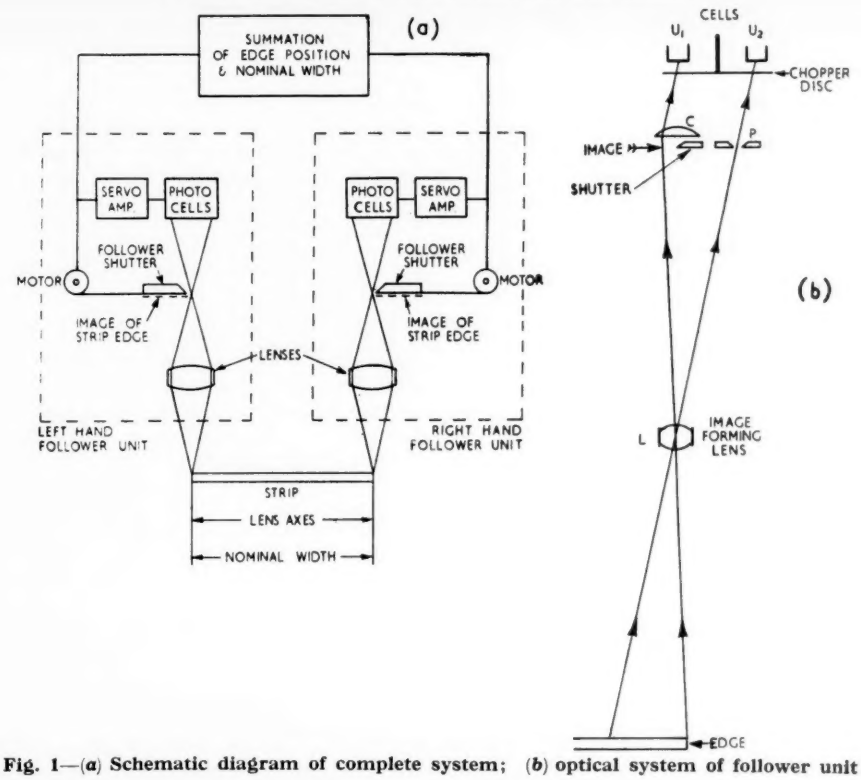


Fig. 1—(*a*) Schematic diagram of complete system; (*b*) optical system of follower unit

the edge. This light falls on the photocell, the signal from which operates an electronic unit and motor which move the shutter so as to keep the signal down to the value given by this narrow element of image, which is formed by the radiation from a narrow portion of the hot strip adjacent to the edge. The width of this portion is considerably less than the smallest width of strip which the instrument is required to measure. The position of the shutters can therefore be interpreted in terms of position of each strip edge, and by compounding these indications with the separation of the lens axes, which is set at the nominal width of the strip, the total width of the strip can be determined from moment to moment as it passes through the mill.

In the optical unit the radiation from the strip edge is balanced against the radiation from a fixed area of the strip a short distance in from the edge, a pair of identical photocells being used. This reduces to a negligible degree the errors introduced by variations in cell characteristics with change of temperature of the cell, or of the strip. Also, by using infra-red radiation, the system is not liable to be disturbed by variations in the illumination of the object by visible light. The working of the follower units will now be considered in detail.

THE PROTOTYPE FOLLOWER UNIT

Optical arrangement

The follower unit contains a lens (L, Fig. 1*b*), focal length 10 in., aperture $f/10$, which forms an optical image, using infra-red light, of the appropriate strip edge. This lens is mounted in a tube with provision for coarse focusing by sliding the mount and fine focusing by screwing. The shutter is placed at the infra-red focus of the lens, below a rectangular masking aperture. Just above the masking aperture is a condenser lens C (focal length 2 in., diameter 1 in.) which concentrates the light passing through the shutter on to the photoconductive cell U_1. The servomechanism, actuated by the signal from the cell, moves the shutter to keep the signal down to the small value occasioned by the narrow element of strip ' seen ' by the cell. The value of signal to which the servo controls the shutter position is determined by balancing it against the signal received by an identical cell, U_2, sited close to the first, from an area of strip selected by the small aperture P. In this way the effects of variations in strip temperature and of cell sensitivity caused by ambient temperature are largely cancelled out. The function of the condenser lens is to form an image of the lens, L, on the receiving surface of the lead sulphide cell. By doing this, the infra-red radiation which has already formed an image of the strip edge, moving as the edge moves, is made to fall on a fixed area covering the photocell, and this area varies uniformly in intensity according to the total amount of energy which is allowed to pass by the shutter. A similar effect is obtained with the aperture P, admitting the comparison beam to the cell U_2. Since P is small (about 0·1 in.) compared to its distance from U_2 (about 2 in.), a pinhole image of the lens, L, is formed on U_2. As P does not move,

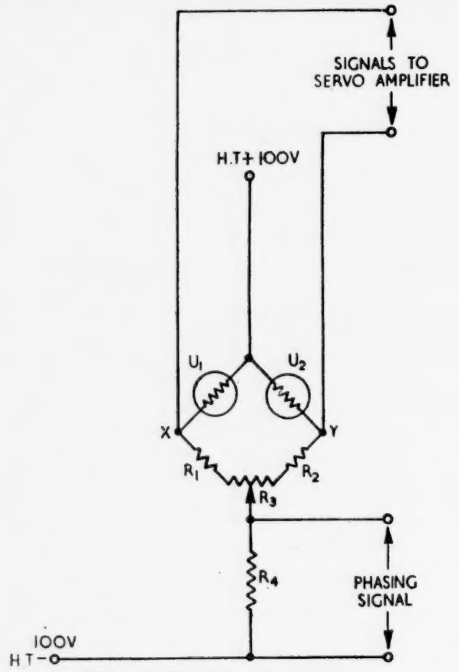


Fig. 2—Bridge arrangement

this adequately reproduces the same effect as does the condenser C on U_1.

Production of signals at 400 c/s

To make use of existing servo equipment adjusted to this frequency, the radiation falling on the cells is interrupted at 400 cycles per second. No suitable synchronous motor was available at this frequency, so a 50-cycle synchronous motor is used running at 3000 rev/min, in conjunction with a chopper disc with 8 teeth. The cells are located diametrically opposite to each other behind this disc. As an even number of teeth is required, this means that the cells are simultaneously covered or uncovered by the disc. The bridge arrangement illustrated in Fig. 2 enables the signals obtained in this way to operate the servo system.

Assuming identical behaviour of cells U_1 and U_2, an equal irradiation of each will produce a 400-cycle alternating voltage of equal amplitude at X and Y. If the cell at X is irradiated more than the other, there will be a larger alternating voltage on X, and vice versa. The main amplifier and phase-sensitive rectifier unit to which the signal is applied are arranged so that the servo motor operated by their output moves to one side or the other according to which cell is receiving the more radiation.

The resistance R_4 carries the current through both arms of the bridge, and a 400-cycle voltage of constant phase is therefore developed across it. This is used as a reference signal and applied to the phasing amplifier controlling the phase-sensitive rectifier.

SERVO AMPLIFIER UNIT

The electronic unit which operates the shutter, following the lead sulphide cells and bridge, is made up of a push–pull amplifier unit (the main amplifier) and the phasing amplifier. The phasing amplifier has

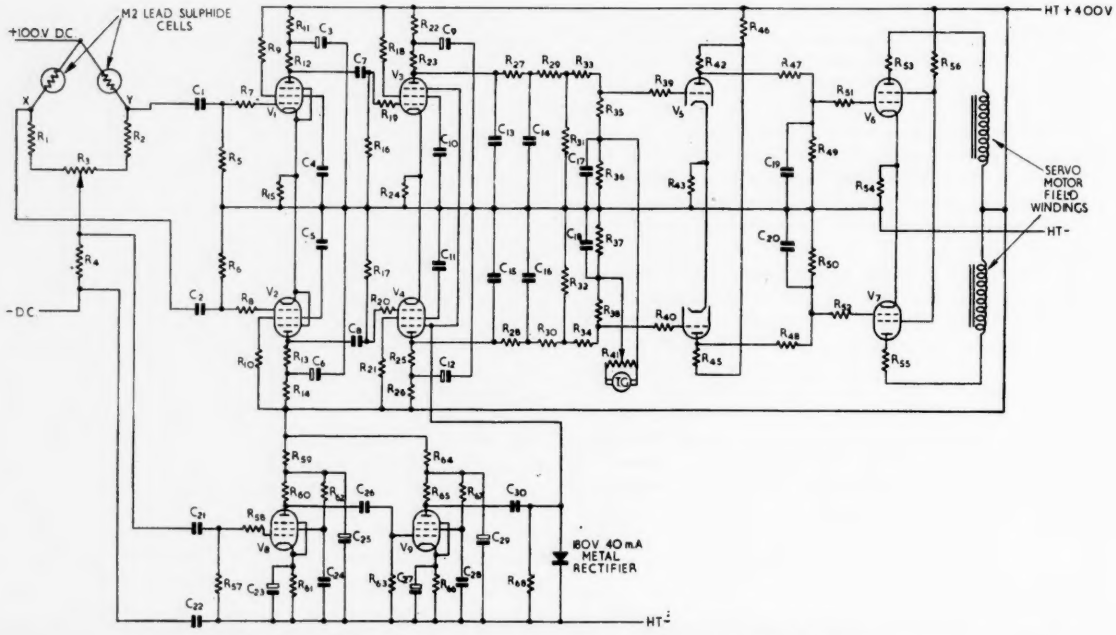


Fig. 3—Circuit diagram for wide-strip width-meter follower unit

two pentodes (EF37A) giving two stages of amplification. The main amplifier (Fig. 3) consists of:

1st 400-cycle stage (two EF37A pentodes),
2nd 400-cycle stage and phase-sensitive rectifier (two EF37A pentodes),
D.c. amplifier stage (one 12AX7 double triode), and
Output stage (two CV 428 tetrodes).

The circuit operates in the following manner. The signals at X and Y of Fig. 3 are 400-cycle alternating voltages of the same phase but different amplitudes. The amplitude depends upon the degree of irradiation of the relative cell. These signals are applied to their respective sides of the balanced amplifier, and amplified by the first and second stages. In the second stage, valves V_3 and V_4, the suppressors have applied to them the phasing signal, which is derived from R_4 and amplified independently. This voltage is in opposite phase to the bridge signals applied to the grids of V_3 and V_4, and is sufficient to cut off the valve having the weaker signal on its grid. Suppose this is V_4. Then the anode current of V_4 is steady at a low value and the anode voltage remains high. The anode voltage of V_3 oscillates at 400 c/s but does not exceed the anode voltage of V_4. This voltage is rectified by V_3 and filtered by the network C_{13}, C_{14} and R_{27}, R_{29}. Then the voltages of V_4 and the lower smoothed voltage of V_3 are applied to the grids of their respective halves of the double triode V_5. The anodes of V_5 are d.c., coupled to the grids of the output valves V_6, V_7, so V_6 on the side with the smaller photocell signal passes the greater current.

It will be noticed that in practice one of the photocells, the comparison cell, is illuminated at substantially the same level throughout, the only variations being those caused by changes in strip temperature, while the irradiation of the measuring cell may vary much more widely in either direction. The phasing voltage automatically adjusts itself to any circumstance, however, since it is amplified from the voltage across R_4, which carries the current through both cells.

The anode currents of V_6 and V_7 pass through the windings of the split-field motor operating the shutter, which accordingly moves to one side or another according to whether the measuring beam is irradiated more or less than the balancing condition.

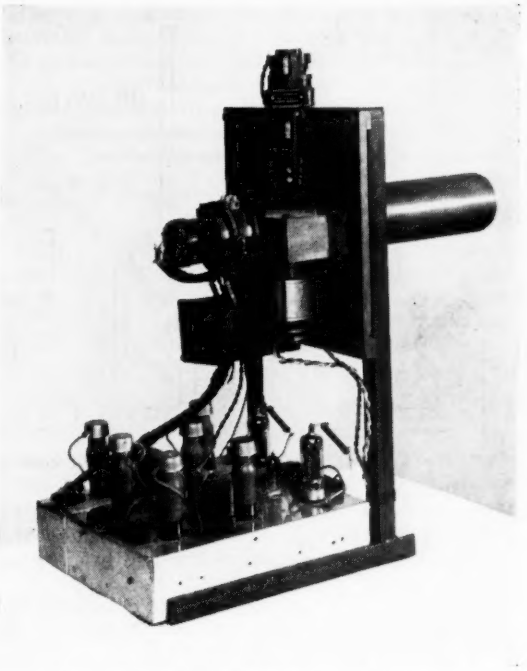
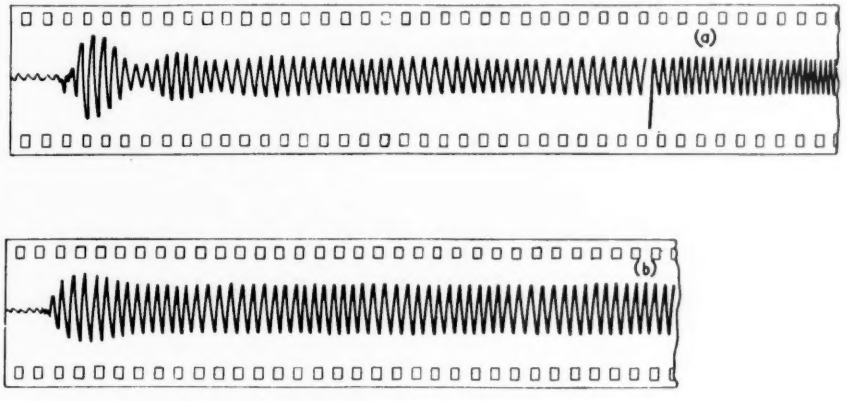


Fig. 4—Experimental follower unit complete

The rectifier network ($R_{27\text{-}34}$; $C_{13\text{-}16}$) also receives a proportion of the output from the tacho-generator linked with the motor, which introduces a velocity feedback signal damping its movement.

SHUTTER ARRANGEMENTS

The spindle of the servo motor is geared to that of a mag-slip with a 4 : 1 reduction ratio. A pair of thin metal tapes are anchored to the spindle of the mag-slip and pass to the shutter, which is an aluminium plate with a rectangular aperture, sliding below a smaller fixed masking aperture. One edge of the



(*a*) Low velocity feedback (*b*) High velocity feedback

Fig. 5—Oscillograms showing speed of response for $\frac{1}{16}$ in. displacement

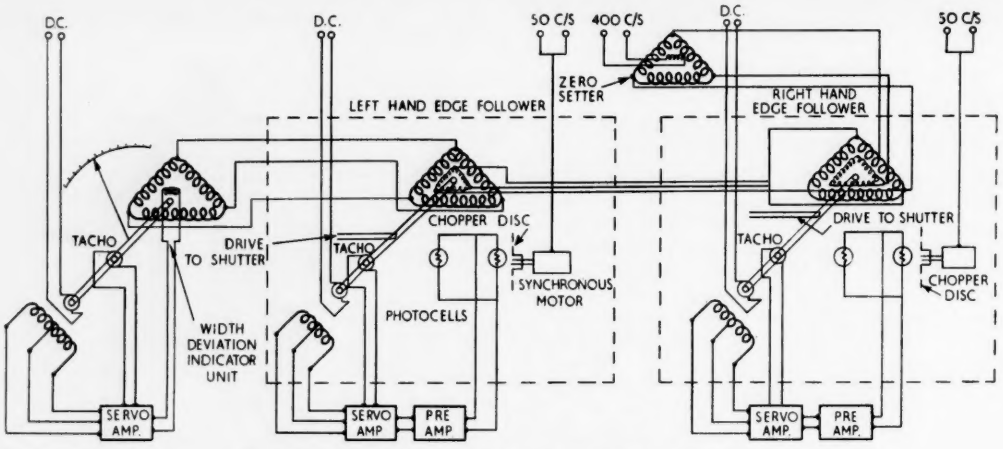


Fig. 6—Method of combining edge-position readings

shutter aperture cuts into the side of the masking aperture on which the image of the strip lies. The tapes pass on round an idler roller, and back to the mag-slip spindle.

The servo motor, in rotating as dictated by the amplifier, moves the shutter so that it obstructs all but a small element of the strip image.

The shutter therefore 'follows' the movements of the strip edge, over a range which depends on the size of the masking aperture and the magnification of the image. In the follower unit built, this magnification was estimated at $\times \frac{1}{10}$ and the masking aperture is 0·6 in. across, so that the movements of the strip edge are followed for about $\pm$ 3 in., which is sufficient for the latitude of movement usually allowed between the guides.

ADJUSTMENTS AND PERFORMANCE

A lead sulphide cell was placed in one arm of a bridge, the output of which was applied to a cathode-ray oscilloscope. The sensitive surface of the cell was placed behind a slit, on which an image of a strip filament was formed so that it exactly filled the width of the slit. The signal from the lead sulphide cell, which showed a certain measure of irradiation at the best visual focus, increased as the slit was moved further from the lens, and reached a maximum when the distance from slit to lens was about 5% greater than the visual focus. This can be taken as the best focus for the radiation to which the cell is sensitive.

Figure 5 illustrates the tests for speed of response. The plates of an oscilloscope were connected across the two ends of a stator of the mag-slip, which was adjusted till the stator had zero potential across it in the first equilibrium position of the system. Any displacement of the motor caused by movement of the follower-unit shutter excited a 50-cycle voltage across the stator. The rate at which this voltage settled to its new value gives the speed of response of the follower unit, which was conveniently measured by photographing the oscillograph trace. Figures 5*a* and *b* show the trace with a low and high value of feedback from the tacho-generator.

The apparent change in strip-edge position was studied by setting up two plates in front of the target, which was an electrically heated element at a temperature (900° C) approximately equal to that of a rolled strip. One plate remained fixed, the other was movable. The rapid removal of this plate simulated an instantaneous change in edge position, of an amount equal to the distance it projected beyond the fixed plate. Its removal simultaneously operates a microswitch which increases the brightness of the oscilloscope beam. In this way the oscillograms photographed record the total time elapsing from the edge displacement till the time that the follower shutter has settled to a new position. The faint trace prior to the edge movement shows a small 50-cycle ripple representing a slight remaining voltage across the stator. When a sufficient degree of feedback is present, only 6–7 cycles elapse before the mag-slip has settled to a value within 10% of its new equilibrium, i.e. an overall delay of less than 0·15 s. For this test a step change of position of $\frac{1}{16}$ in. was employed, and movements of $\frac{1}{64}$ in. were detectable.

The follower as built can therefore be expected to indicate the position of the strip edge over a range of about 6 in. with an accuracy of $\pm \frac{1}{16}$ in. The limiting sensitivity, which as the tests showed was normally at least $\frac{1}{64}$ in., will vary to a slight extent depending on the temperature of the hot strip and the variations with ambient temperature of the lead sulphide cells. Within this limit the shutter will follow accurately throughout its range of movement.

SUBSEQUENT DEVELOPMENT

The application to a rolling mill of an instrument incorporating the above principles requires a considerable amount of heavy engineering and must be worked out in relation to the actual mill to which it is to be fitted. The further development of the instrument was accordingly handed over to a commercial firm.

The development of the complete instrument must have two main objects, to produce means of positioning the follower units above the strip edges, with arrangements to alter their position for different basic widths of strip, and to devise means of combining the position readings of the two followers into

a single reading of strip width. This development must take account of the prevailing mill conditions of temperature, vibration, and air pollution, and incorporate protection against these where necessary.

A simple way of positioning the follower units is to mount them on a lead-screw with opposite threads for right and left hand units, or to have two similar lead-screws, one for each unit, geared together to rotate in opposite directions. This assumes a symmetrical closing in of the guides for a decrease in the width of strip rolled. In the latter case the linkage of the lead-screws could be interrupted to give independent positioning. More versatile, but expensive, would be a method of making the electrical signals perform a coarse adjustment by bodily movement of the follower units as well as the fine measurement performed by moving the internal shutter. Circuits could be incorporated in which a movement of the shutter a certain distance away from its central position initiated the action of a motor, driving the follower in the appropriate direction till the shutter was brought back within those limits, i.e. above the strip edge in its new position.

A number of different methods are available, using techniques and components which are now standard, for combining the readings of the two follower units. One such method, using mag-slips, is illustrated in Fig. 6. The windings of the transmitter of the right-hand mag-slip, as drawn, are connected in parallel to the stator windings of the mag-slip in the left-hand follower unit, which must be of the follow-through transmitter type. The signal transmitted by the latter will make the third mag-slip in the width-deviation unit take up a position which is a mean of the position of the other two. (The first two mag-slips must be connected so as to reverse the sign of one, since equal shutter displacements of the same sign infer no change in strip width.) The position of the zero can also be given a fine adjustment as shown, by feeding another signal on to one of the mag-slips. Since this summation is electrical, no further delay or friction is introduced.

Strip-width meters based on these broad principles have been built and installed by Evershed and Vignoles Limited and Davy and United Engineering Co., Limited. In both cases the tape-driven shutter has been replaced by a rotating shutter, since the long-term reliability of the tape drive was thought to be very doubtful.

CONCLUSION

As a result of a need voiced by the industry, the fundamental work done by B.I.S.R.A., has demonstrated the feasibility of the proposed instrument, and has led to the development of commercial versions.

Acknowledgments

The authors gratefully acknowledge their indebtedness to the Steel Company of Wales Limited, who suggested the development of a strip-width meter and supplied background information and facilitated visits to works, and to Mr. S. S. Carlisle, who was responsible for the original conception of the instrument.

A Contribution to the Study of Anomalies in the Internal Friction of Iron due to the Presence of Nitrogen in Solution

By L. Guillet and P. Gence

SYNOPSIS

The behaviour of a low-carbon steel when subjected to cyclic stresses at various temperatures is studied. Peak values of internal friction are related to the resonant oscillation of nitrogen atoms in the α-iron lattice. Critical temperatures for maxima in internal friction at frequencies from 322 to 15,000 c/s are determined. A comparison is made between the calculated and experimental values of the relaxation time for the range of temperatures studied. 1330

INTERNAL FRICTION is manifested by the damping which occurs in a freely vibrating object when the latter is suspended in such a way that no energy can escape to the surroundings, especially via the suspension. When such a specimen is subjected to an oscillating stress, the internal friction prevents the amplitude of vibrations from rising to prohibitive values when the frequency of oscillation approaches the natural frequency of the specimen. To specify the internal friction quantitatively either the coefficient of damping K, which is the ratio of the amplitudes of two successive oscillations, or the logarithmic decrement δ can be used. It has been shown experimentally that these two quantities are independent of the amplitude, providing the latter is relatively small. The following relationships therefore apply:

$$K = \frac{A_n}{A_{n+1}} = \frac{A_0}{A_1}$$

$$\text{and } \delta = \log_e \frac{A_0}{A_1} = \log_e K$$

where A_0 = initial amplitude, and A_n = the amplitude after n complete oscillations. It has been known for a long time that annealed low-carbon steels exhibit

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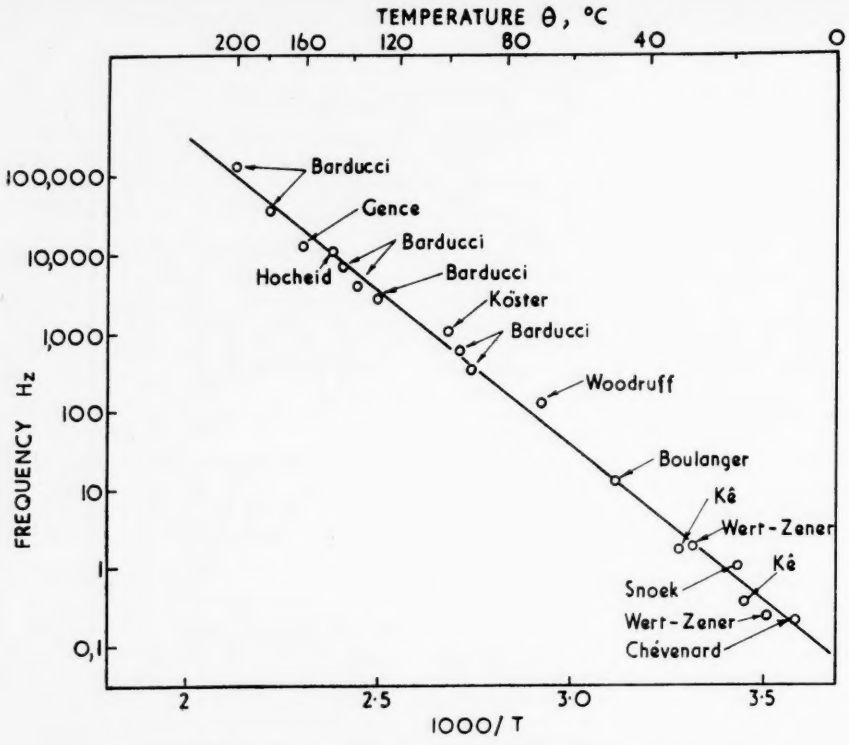


Fig. 1—Comparative plot of previous determinations of internal friction peak

anomalous values of internal friction when heated[1] and that the temperature at which the anomaly is a maximum is a function of the frequency of oscillation used in the experiments.[2]

These effects can be attributed to anelastic behaviour associated with variations in the position of nitrogen atoms in α-iron; these atoms are normally distributed at random, but tend to assume specific lattice positions when the specimen is stressed. When a tensile stress is applied to the steel, nitrogen atoms move to positions of minimum energy in the lattice, namely those positions where the interstitial volume has increased, and these will be situated close to the direction of the applied stress. There is however a certain time interval necessary for the nitrogen atoms to move to their new equilibrium positions, and this prevents the lattice strain from following the applied stress instantaneously. The time-lag between strain and stress, measured in seconds, is known as the relaxation time. When submitted to the influence of cyclic stresses, nitrogen atoms will therefore move from one equilibrium position to another with the same frequency as the stress, but out of phase with the stress.

When steel is heated, the mobility of nitrogen atoms increases and the relaxation time correspondingly decreases, both following an exponential law. For a certain critical temperature the relaxation time will be of the same order as the time interval between successive peak stresses (the stress varying sinusoidally), and it can be demonstrated that the internal friction will then pass through a maximum.[3] At the critical temperature T, the annular frequency of the stress ω, and the relaxation time τ must satisfy the relationship:

$$\omega.\tau = 1 \quad \ldots\ldots(1)$$

but $$\tau = \tau_0 e^{U/RT} \quad \ldots\ldots(2)$$

therefore $$e^{U/RT} = 1/2\pi f \quad \ldots\ldots(3)$$

where U = the activation energy of diffusion for nitrogen in α-iron
R = gas constant
f = frequency of oscillation (c/s)
τ_0 = relaxation time at $T = \alpha$

There should therefore be a straight-line relationship between the logarithm of the frequency and the reciprocal of the temperature (° K) of the internal friction peak.

The experimental results of many workers (Fig. 1) have confirmed this relationship. In the present work the authors have determined the temperatures of the internal friction peak for a steel containing 0·02% C, and 0·004% N_2, over a range of frequencies from 300 c/s to 15,000 c/s (Table I).

Table I

TEMPERATURE OF INTERNAL FRICTION PEAK FOR 0·02% C + 0·004% N STEEL

Frequency, c/s	Critical temperature, °C
322	91
505·8	97
2696·5	128
4286	137
6607	142
15072	161

These results were obtained by inducing longitudinal or transverse vibrations in a test piece by an electrostatic method. The apparatus used, designed by Cabarat,[4] is based on the excitation of longitudinal vibrations in a specimen 150–250 mm in length and 8–12 mm in diameter, held in the centre by three hardened steel needles which position the specimen between two adjustable electrodes A and B (Fig. 2).

Electrode A receives the amplified voltage output* of a low-frequency generator, and the alternating electrostatic field induces longitudinal vibrations in the specimen. To avoid short-circuiting between the electrode and the upper part of the specimen, a small insulating disc (0·1 mm thick) of quartz has been interposed. Electrode B receives 100 V d.c. and acts as an electrostatic microphone or receiver. The output of electrode B is amplified and fed to a cathode-ray oscilloscope, or it can be measured with a voltmeter. The specimen is earthed. The amplitude of induced vibrations is negligible unless the frequency of the electrostatic impulses equals the natural frequency of the specimen; this is attained by adjusting the variable condenser of the generator to give different frequencies between the electrode A and the earthed specimen. When the critical frequency has been obtained, the amplitude of vibrations registered on the oscillograph reaches a sharply defined maximum. The instrument registering the frequency of the output of the generator is accurately calibrated and will therefore give the natural frequency F_0 of the specimen when a maximum deflection is observed on the oscilloscope.

The procedure necessary to measure the logarithmic decrement involves the determination of the variation of resonance with frequency in the vicinity of the natural frequency. The frequency is varied by adjustment of the variable condenser as before, and the associated amplitude of vibration of the specimen is measured on the voltmeter for each frequency. It can easily be shown that:

$$\delta = \pi \frac{\Delta F}{F}$$

where ΔF is the difference in frequency associated with a drop in amplitude of $\frac{A_0}{\sqrt{2}}$, and A_0 is the maximum observed amplitude.

Loss of energy by the radiation of sound waves from the ends of the specimen may cause appreciable errors in the determination of internal friction and provision has therefore been made for the evacuation of that part of the equipment housing the electrodes and the specimen to a pressure of 0·1 mm Hg.

This apparatus allows the frequency to be measured to an accuracy of $\pm$ 1 c/s in the range 5000–15,000 c/s, but to extend the range of frequencies available for measurement of internal friction a second apparatus producing transverse vibrations was also used (Fig. 3). Resonant frequencies are much lower under such conditions than in longitudinal vibration, and resonance was obtained at frequencies as low as 100 c/s.

In this method the specimen is suspended by two fine brass wires attached to two small rollers which can move freely along two horizontal rails placed above and parallel to the axis of the specimen. The suspension wires are attached to the specimen at the vibrational nodes to reduce losses of energy to the support to a minimum. The position of the nodes can be easily calculated. Electrodes, attached to insulated steatite rollers, are placed at the position of the antinodes by sliding the rollers along the rails used to suspend the specimen. Maximum induced amplitudes are obtained if the electrodes are positioned at the antinodes.

Figure 4 shows the variation of internal friction with temperature in a specimen vibrating at a frequency of the order of 15,000 c/s. With a knowledge of the activation energy for diffusion of nitrogen in α-iron, which can be taken as 18,200 cal/mole,[6, 7, 8] it is possible to estimate this curve theoretically. It is only necessary to know the co-ordinates of the

*700 V d.c. plus effectively 500 V a.c.

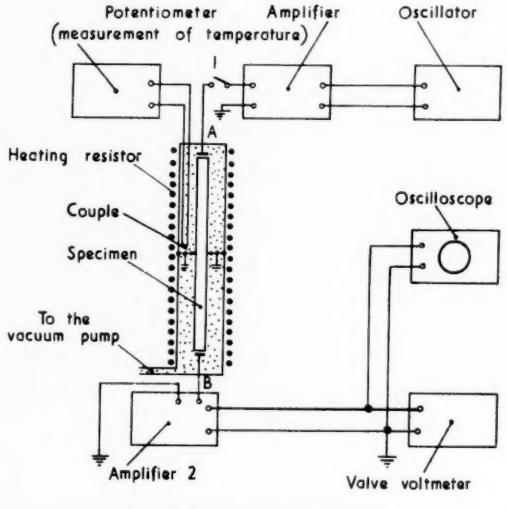
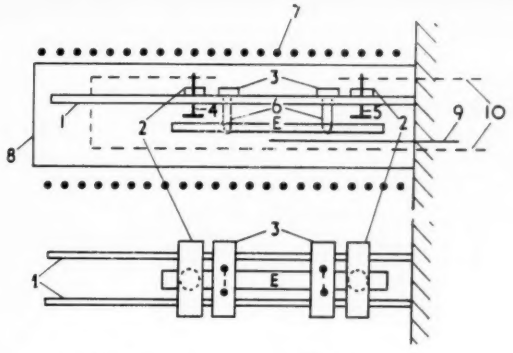


Fig. 2—Vibration apparatus



1 slide rails
2 electrode supports
3 specimen supports
4 excitative electrode
5 microphone electrode
6 brass hanger wires
7 heating coil
8 vacuum pan
9 thermocouple
10 current to electrodes

Fig. 3—Support of specimen for transverse vibations

Table II

COMPARISON OF EXPERIMENTAL AND CALCULATED RESULTS

Critical Temperature, °C	Frequency, c/s	$\frac{U}{RT}$	$e^{U/RT}$	$\tau \times 10^8$	$\omega\tau$	$(\omega\tau)^2$	$\frac{\omega\tau}{1+(\omega\tau)^2}$	δ (theoretical) $\times 10^4$	δ (experimental) $\times 10^4$
111	15,236	23·937	$2{\cdot}4890 \times 10^{10}$	16·559	15·85	251·29	0·063	15·2	11·9
121	15,192	23·330	1·3552	9·0158	8·61	74·06	0·115	21·3	20·5
135	15,160	22·529	$6{\cdot}0830 \times 10^9$	4·0469	3·85	14·86	0·243	36·7	35·8
145	15,126	21·990	3·5485	2·3607	2·24	5·034	0·372	51·8	50
156	15,088	21·426	2·0288	1·3497	1·28	1·637	0·485	65·5	65·5
161	15,072	21·179	1·577	1·0491	1	1	0·5	67·5	63·5
165	15,062	20·986	1·3002	0·8650	0·82	0·670	0·49	66·3	61·5
176	15,030	20·472	$7{\cdot}7764 \times 10^8$	0·5173	0·49	0·239	0·394	55·9	58·5
189	14,996	19·896	4·3715	0·2908	0·274	0·0751	0·255	40·0	42
197	14,966	19·557	3·1146	0·2072	0·195	0·0380	0·188	32·8	32·8
204	14,952	19·270	2·3376	0·1555	0·146	0·0213	0·143	27·9	25·2
220	14,900	18·645	1·2512	0·0832	0·078	0·0078	0·077	17·3	18·5

maximum found in the experimental curve, which have been found to be:

$$\delta_{max} = 67{\cdot}5 \times 10^{-4},$$
$$T\delta_{max} = 161 + 273 = 434° \text{ K},$$
$$(F = 15072 \text{ c/s})$$

Equation (3) allows the calculation of the relaxation time τ_0 corresponding to $T = a$, and the present data leads to a value:

$$\tau_0 = 6{\cdot}65 \times 10^{-15} \text{ seconds}$$

With this information it is possible to deduce the relaxation time appropriate to any temperature T, using equation (2), while the logarithmic decrement δ_T is given by the following relationship:

$$\frac{\delta}{2\delta_{max}} = \frac{\omega\tau}{1+(\omega\tau)^2}$$

Table II gives full details of the necessary calculations, and the close correspondence between the calculated and experimental results is shown in Fig. 4.

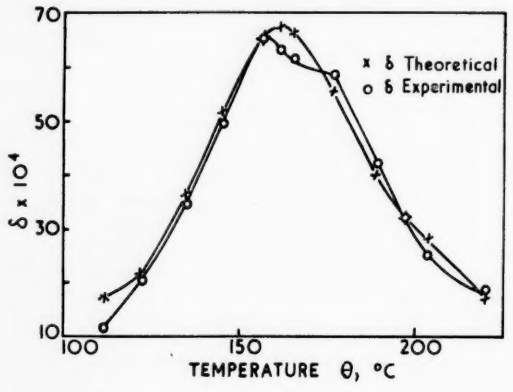


Fig. 4—Variation of internal friction with temperature

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Influence of Slag Properties on Pig-iron Composition

By A. J. Burgess and B. G. Baldwin

SYNOPSIS

An account is given of the results obtained during a blast-furnace trial at the Steel Company of Wales to study the relation between metal composition and slag properties. 1391

FOR SEVERAL YEARS the blast-furnace plant of the Steel Company of Wales has produced basic pig iron with a sulphur content of $< 0{\cdot}03\%$ and a silicon content of 0·4–0·6%. These results have been achieved by the use of slags of high basicity which give a high distribution of sulphur between slag and metal. It was considered that a trial in which particular attention was paid to the measurement of the composition and temperature of the slag and metal at every cast over a period of several weeks would provide valuable information on the practice and would be of interest to other operators.

The trial was carried out at No. 1 blast-furnace over a period of three weeks. During the first week no alteration to normal practice was made. During the second week the slag basicity was deliberately altered by reducing the limestone charged, in order to run at a higher level of sulphur in the iron. During the third week the basicity and the sulphur level in the iron were returned to normal. This allowed a wider range of slag compositions to be studied than if normal practice had been maintained throughout and also enabled information to be obtained concerning the ease, or otherwise, of changing the sulphur level in the iron.

The aim of the trial was to investigate the relation between the metal composition and slag properties and data were collected from every cast and flush throughout the three-week period of the trial.

FURNACE PRACTICE

No. 1 blast-furnace (hearth diameter 21 ft 6 in.) was ' blown in ' on August 13th, 1953, on its second campaign. Prior to the start of the trials, the furnace had made 542,376 tons of basic iron, with a throughput of 1,193,022 tons of ore, 96,102 tons of limestone, and 444,857 tons of coke.

The furnace produces basic iron of the following mean analysis:

Si, %	S, %	P, %	Mn, %
0·5	< 0·03	0·50	1·5

The principal components of the burden are: raw unscreened Oxfordshire 25%, sinter 35%, soft Mediterranean ore 15%, and Swedish 12·5%. All foreign ores are crushed and screened. Primary crushing produces a — 2-in. product and the feed is scalped at 1 in. Most ores handled are below 10 in. maximum size and the majority is — 6 in. as received. The crushed ores and scalpings are passed over a 1-in. primary screen and a $\frac{3}{8}$-in. secondary screen. The oversize from all screens is used at the blast-furnace and the undersize at the sinter plant. Slag volume varies between 12 and 13 cwt/ton of iron. Unscreened limestone and magnesian limestone are used as fluxes, close control being exercised to provide slags of high desulphurizing power.

Approximately 90% of the coke used is produced in the Company's own coke ovens, and the remainder is purchased from local sources. The coke is of good metallurgical quality, the mean analysis being:

FC, %	VM, %	Ash, %	S, %	P, %	H_2O, %
88·88	0·73	10·40	1·10	0·054	4·20

During the trial the furnace was tapped five times per day at scheduled times. One hour after the completion of casting slag was tapped until blowing occurred at the slag notch and subsequently tapped at half-hourly intervals before the next cast.

The ores and sinter were used as available and no abnormal alterations in burdening were made. The limestone addition was reduced rather than the magnesian limestone during period 2 in order to maintain a fluid slag. The magnesia was increased during period 3 in order to reach the optimum slag

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Mr. Burgess is Blast-Furnace Manager at the Steel Company of Wales, Ltd., and Dr. Baldwin is at the Blast-Furnace Laboratory, Imperial College of Science and Technology, London.

composition having the best balance between viscosity and desulphurization for the alumina content of the slag. The maximum distribution ratio of sulphur between slag and metal achieved was 144. The deliberate alterations made to the slag basicity permitted a change in the weekly average % S in the iron from 0·02 to 0·04 and back to 0·02 to be made; these changes were made without encountering any operating difficulties. The mean blast temperature was 610° C and blast volume 47,300 ft³/min. The furnace was off blast for 19 h during period 3 during a planned shutdown.

EXPERIMENTAL TECHNIQUES EMPLOYED

In any blast-furnace trial a compromise has to be made between what it is possible to measure and what it is desirable to measure. In addition to the routine data collected by the works' staff, for the period of the trial the following additional information was obtained: iron temperature, roughing-slag temperature, flushing-slag temperature, analysis of roughing and flushing slags for MnO and S, complete analysis of many roughing-slag samples, the S content of the coke and flue dust, and slag weights.

IRON TEMPERATURE AND SAMPLING

The temperature of the iron was measured by the standard quick immersion method using Pt–Pt/13% Rh thermocouples protected by a thin silica sheath. The couple was connected to a Honeywell-Brown 1200–1750° C indicator/recorder. It was found possible to take several iron temperatures with one sheath but normally the sheath was replaced after every second dip.

The samples of iron were collected and temperatures were measured immediately after the skimmer, some 27 ft from the tap-hole. Here there was considerable movement in the liquid iron and always a suitable depth for the dip measurements. A portable metal screen was erected to give some measure of protection, and this was particularly valuable towards the end of a cast when there was some blowing at the tap-hole.

If an accurate measure of the carbon content of pig iron is required, it is essential to cool the sample sufficiently rapidly to prevent free graphite formation and subsequent loss during crushing. The method used during the trial was to pour the metal into a split steel mould having a high heat capacity which ensured rapid quenching of the iron. As an example of the errors possible in the determination of carbon, a spoon sample of iron was sampled in four different ways: (*a*) pouring into a split steel mould, (*b*) pouring into water, (*c*) pouring into a sand mould, and (*d*) pouring into an open steel mould:

Type of sample:	(*a*)	(*b*)	(*c*)	(*d*)
C, %	4·31	4·25	4·09	3·96

It can be seen that the rapid quenching of methods (*a*) and (*b*) gave higher values of the total carbon content than methods (*c*) and (*d*).

Samples were taken on an equal volume basis by judging the volume of iron in the Kling ladles. It was only possible to have one sample of iron per cast for final analysis. The question to be decided was how many increments should be used in preparing this average sample. In order to study this point one cast was sampled at 14 equal volume increments. Using the data obtained from all 14 samples, the results obtained were as follows:

Element:	C	Si	S	P	Mn
%:	4·6	0·47	0·01	0·48	1·74
Standard deviation (σ):	0·05	0·04	0·002	0·02	0·03

It is possible to calculate the effect of taking a smaller number of samples than 14, and the following results are obtained.

No. of Samples	Difference from True Mean (5% Probability) $1{\cdot}96\sigma/\sqrt{n}$				
	C	Si	S	P	Mn
1	0·098	0·078	0·004	0·039	0·059
2	0·069	0·055	0·003	0·028	0·042
3	0·057	0·045	0·002	0·023	0·034
4	0·049	0·039	0·002	0·020	0·029
5	0·044	0·035	0·002	0·018	0·026

On the basis of these results it was decided that the mean of three samples would be sufficient; it was, however, decided to aim during the cast at four samples at equal volume intervals to ensure that at least three samples were always available for final mixing to provide the sample for analysis. The temperature of the iron was measured at the time each sample was taken, and from this an average iron temperature for the cast was obtained.

A very marked rise in temperature of the metal occurred when slag began to flow freely out of the tap-hole. The amount of roughing slag was very variable and the metal temperature was found to depend on the amount of roughing slag. Casts where little or no roughing slag came over with the iron usually had a lower metal temperature than average. It is for this reason that flushing-slag temperature is considered to be a better measure of the temperature at the slag/metal interface than metal temperature. The mean metal temperature was found to be significantly correlated with the flushing-slag temperature but the variance explained was not very high (16%). The results are shown below:

Correlation Coefficient, r	Regression Coefficient, b	Residual Standard Deviation, ° C	
0·38	0·27	22	3·6

A brief description of the statistical principles used in this report is given in the Appendix.

SLAG TEMPERATURE AND SAMPLING

The same equipment was used for measuring slag temperatures as for the iron. It was essential to replace the silica sheath after each dip. Roughing-slag temperatures were taken just above the skimmer and the samples some 12 ft down the slag runner. Flushing-slag samples and temperatures were taken in the runner about 18 ft from the slag notch. The slag was liable to cool considerably between the notch and the measuring point unless flowing rapidly. Care was taken to obtain slag temperatures only when this latter condition was realized. A number of roughing-slag temperatures were measured immediately after that of the iron coming with it from the furnace; in no case was the difference between the two greater than 10° C and it was usually 5° C or less. Roughing-slag temperatures were therefore not

measured at every cast but assumed to be that of the iron at that time. It is evident that during the passage through the tap-hole the slag and metal come into thermal equilibrium.

All samples of slag were taken by a spoon and poured into a Herty-type viscometer.[1] The number of slag samples which should be taken was determined in a similar way to that described for iron by analysing a large number (16) of samples obtained during one cast. The results again indicated that three samples of slag were necessary and sufficient.

Component:	SiO_2	Al_2O_3	CaO	MgO	MnO	S
%:	29·5	14·6	40·8	11·7	0·75	1·30
Standard deviation (σ):	0·72	0·48	1·18	0·19	0·09	0·06

The samples obtained from each flush of slag were mixed together in proportion to the amount of slag obtained at each flush to obtain a sample representative of the slag coming over between casts and this was analysed for S and MnO only. The samples of roughing slag obtained during a cast were mixed together and analysed for S and MnO. A complete analysis of daily samples was made. In addition samples from 37 individual casts were analysed completely. Analyses were carried out in the laboratories of the Steel Company of Wales using standard analytical techniques and were supported by confirmatory analyses carried out by B.I.S.R.A.

RESULTS OBTAINED

Sulphur Balance

From knowledge of the analysis of the ingoing and outgoing materials and their weights, obtained from the normal works' records, a sulphur balance was drawn up and is shown in Table I. From this it can be seen that there is a loss of sulphur between the ingoing materials and the outgoing solid products; this is 12·7%, 11·5%, and 5·4% for the three periods respectively. This is probably due to loss of sulphur from the furnace in the blast-furnace gas. Calculations for period 2, based on the wind blown and the tons of sulphur unaccounted for, give a value of 0·1 grains of sulphur/ft^3 in the blast-furnace top gas, which is not unreasonable.

Further examination of Table I shows that during each of the three periods the coke contributed about 90% of the total sulphur load on the furnace. Particular attention was therefore paid to the measurement of the coke sulphur. This was done once each shift from composite samples taken during each shift. During the three periods the following results were obtained:

	Period 1	Period 2	Period 3
% S in the coke:	1·12	1·16	1·12
Standard deviation:	0·04	0·06	0·05

These agree reasonably well with the average works' data quoted earlier.

It can be seen from Table I that the charging of a relatively small amount of basic slag for reasons of

Table I
SULPHUR BALANCE OF INGOING AND OUTGOING MATERIALS

Ingoing Materials	Period 1				Period 2				Period 3			
	Tons	%	S, tons	S as % of Total	Tons	%	S, tons	S as % of Total	Tons	%	S, tons	S as % of Total
Foreign ore	3736	24·6	1·87	3·9	3230	22·6	1·58	3·6	3939	29·6	1·83	4·5
Manganese ore	124	0·8	0·15	0·3	108	0·8	0·13	0·3	106	0·8	0·13	0·3
Oxfordshire ore	2803	18·5	1·12	2·3	2642	18·5	1·06	2·4	2413	18·1	0·96	2·3
Sinter	3231	21·3	0·55	1·2	3795	26·5	0·65	1·5	2192	16·4	0·50	1·2
Scrap	...	...	...	...	...	...	...	...	...	...	...	...
Basic slag	411	2·7	0·99	2·1	397	2·8	0·95	2·2	334	2·5	0·80	2·0
Total ores etc.	10305	67·9	4·68	9·8	10172	71·0	4·37	10·0	8984	67·4	4·22	10·4
Limestone	359	2·4	0·25	0·5	64	0·5	0·05	0·1	74	0·6	0·05	0·1
Magnesian limestone	726	4·8	0·36	0·8	730	5·1	0·36	0·8	1090	8·2	0·55	1·3
Coke	3796	25·0	42·50	89·0	3352	23·4	39·00	89·1	3184	23·9	35·70	88·0
Total burden	15186	100	47·79	100	14318	100	43·78	100	13332	100	40·52	100
Outgoing Materials												
Iron	4452	57·9	1·02	2·4	4820	62·4	1·78	4·6	4117	59·0	0·82	2·1
Slag	3180	41·4	40·60	97·2	2830	36·6	36·80	95·0	2800	40·2	37·80	97·6
Flue dust	59	1·0	0·1	0·3	75	1·0	0·15	0·4	57	0·8	0·11	0·3
Total solid products	7691	100	41·74	100	7725	100	38·73	100	6974	100	38·73	100
S, % not accounted			12·7				11·5				5·4	

Table II
METAL ANALYSIS

Period		C, %	Si, %	S, %	P, %	Mn, %	Temp., °C
1	Mean	4·1	0·70	0·023	0·53	1·41	1420
	Standard deviation	0·13	0·25	0·003	0·03	0·15	36
2	Mean	4·25	0·51	0·037	0·50	1·35	1420
	Standard deviation	0·07	0·15	0·009	0·03	0·17	19
3	Mean	4·30	0·45	0·020	0·51	1·51	1435
	Standard deviation	0·12	0·15	0·009	0·03	0·20	21

manganese conservation contribute about 2% of the total sulphur load on the furnace.

Metal Analyses

The mean metal analyses for the three periods and their standard deviations are shown in Table II. No difficulty was found in increasing or decreasing the sulphur content in the iron. The first period represents a week with a normal burden. The mean S content during this week was 0·023% with a standard deviation of 0·003. This indicates how little the S content of the iron varied under normal operation, as only 1 in 20 casts would be expected outside the range 0·029–0·017% S (i.e. mean $\pm 1{\cdot}96 \times$ standard deviation).

There were considerable variations in the mean temperature of the metal from cast to cast, as is indicated by the value of the standard deviation, and in general a steady rise in temperature occurred during the cast, the rate of increase increasing when slag appeared with the iron. The average rise in temperature was 40° C during the cast, although rises between 10° and 100° C occurred. The highest iron temperature recorded was 1515° C and the lowest 1340° C.

Slag Analysis

The mean slag analysis, temperatures, and Herty Index of the slags and their standard deviations are shown in Table III for the three periods. The $(CaO + MgO)/(SiO_2 + Al_2O_3)$ ratio was 1·01, 0·92, and 1·01 for the three periods respectively, the reduction in period 2 being due to the removal of limestone from the burden. The mean temperatures of roughing and flushing slags increased during the time of the trial. As has been mentioned earlier, the mean iron temperature also followed the same pattern, and it would seem that the hearth was hotter at the end of the three weeks than at the beginning. The flushing slags were found to be about 80° C hotter than the roughing slags and about 100° C hotter than the iron. The highest flushing-slag temperature recorded was 1600° C. The Herty Index of the flushing slag was higher than that of the roughing slag and each increased during the trial period.

Comparing the S and MnO contents of the roughing and flushing slags, it can be seen that there are differences between the two. Statistical examination of these differences gave the following results:

(*a*) *Sulphur*, % (*mean*)

Period	Roughing Slag	Flushing Slag	Significance of the Difference
1	1·23	1·30	Not significant
2	1·21	1·35	Highly significant
3	1·32	1·37	Significant
1 + 2 + 3	1·25	1·35	Highly significant

There is thus a general tendency for the sulphur in the flushing slag to be greater than in the roughing slag. During period 2, when the sulphur content in the metal was raised, this tendency was greatly increased.

(*b*) *Manganese Oxide*, % (*mean*)

Period	Roughing Slag	Flushing Slag	Significance of the Difference
1	1·39	1·31	Not significant
2	1·89	1·60	Highly significant
3	1·27	1·28	Not significant
1 + 2 + 3	1·52	1·40	Significant

There is a difference between the MnO content of the roughing and flushing slags during period 2, when the S content of the metal was higher than normal, but this is not apparent during the other periods. There is also a very great difference between the mean slag MnO over the three periods. This indicates that more sulphur is removed and less manganese is lost when slag is run off during flushing than during casting. There are two reasons that could account for these differences: firstly, the intimate mixing of hot slag and cold metal which occurs during casting could cause a reversion of sulphur from slag to metal, and of manganese from metal to slag to take place due to the fall in temperature; secondly, since the furnace was on full blast until just before the end of a cast, metal and slag were being produced in the furnace during casting and these would have little time in contact before leaving the furnace. Hence

Table III
SLAG ANALYSIS

Period		Roughing Slag								Flushing Slag			
		SiO_2, %	CaO, %	MgO, %	Al_2O_3, %	S, %	MnO, %	Temp., °C	Herty Index	S, %	MnO, %	Temp., °C	Herty Index
1	Mean	31·7	41·0	7·3	15·9	1·23	1·39	1420	2·7	1·30	1·31	1505	3·3
	Standard deviation	0·8	1·5	0·9	0·4	0·12	0·22	23	0·6	0·14	0·30	23	0·7
2	Mean	33·3	36·2	9·8	16·6	1·21	1·89	1430	2·8	1·35	1·60	1525	3·9
	Standard deviation	2·1	1·9	1·4	0·4	0·11	0·31	20	0·59	0·11	0·25	16	0·7
3	Mean	31·5	39·4	9·0	16·5	1·32	1·27	1455	3·5	1·37	1·28	1530	4·1
	Standard deviation	1·1	1·6	1·0	0·3	0·06	0·38	28	1·2	0·10	0·36	36	0·9

partition of S and Mn between slag and metal may not have been as complete as would be possible with a longer time of contact in the hearth. However, data obtained from three casts, in which many roughing-slag and metal samples were collected and analysed, gave no significant trend in the S and Mn contents. This would seem to indicate that partition of S and Mn occurred without a prolonged time of contact in the hearth. Any method of increasing the proportion of flushing slag to roughing slag would be of benefit.

If any attempt is made to correlate the distribution of sulphur and manganese between slag and metal, it is important to realize that these differences exist, and it would seem that the higher the sulphur content of the metal is, the more important the differences become. In view of the fact that the proportion of roughing slag to flushing slag is very variable, it would seem advisable to sample both roughing and flushing slags in any study of the sulphur distribution between slag and metal, as was done during this trial.

Relationship between Metal Composition and Slag Properties

Carbon—Although the carbon content of basic pig iron is not normally measured at every cast, it is important in foundry practice and from the theoretical viewpoint. Carbon is the principal alloying element in pig iron and strongly affects the activity of sulphur in the metal. The carbon content of pig iron heated in a carbon crucible under laboratory conditions depends on the silicon, phosphorus, and manganese contents of the iron and also on the temperature. The relatively low S content of pig iron has little effect on carbon solubility. For every 1% of silicon and phosphorus the carbon percentage is reduced by 0·3. For every 1% of manganese the carbon percentage is increased by 0·1. The maximum amount of carbon present in pure iron at 1500° C is 5·15% and this is reduced by 0·025% for every 10° in the 1500–1400° C region.[2] Using these data and those obtained during the trial, the theoretical maximum carbon content which the pig iron could have contained has been calculated for each cast. The carbon

$$\left(\frac{\text{actual percentage carbon}}{\text{theoretical maximum percentage carbon}} \times 100\right)$$

saturation for the three periods and for the whole trial are shown below:

Period	1	2	3	1 + 2 + 3
Carbon saturation, %:	87·8	89·3	88·4	88·5
Standard deviation:	4·0	2·1	2·5	2·8

Thus the metal flowing from the furnace contains nearly 90% of the maximum carbon theoretically possible. The mean metal temperature used for the above calculations is, however, dependent on the amount of roughing slag coming over with the iron, as has been mentioned already. During the rapid rise in metal temperature, which occurs owing to mixing with slag in the tap-hole throughout the latter stages of casting, there is no opportunity for the metal to pick up more carbon, and it is therefore unlikely that the iron will be saturated during this period.

Kish was present at only five of the 91 consecutive casts studied, all during period 3, when high basicities and temperatures were encountered. The formation of kish was strongest at the beginning of the cast and disappeared soon after the appearance of slag. Although calculations of the carbon saturation percentage based on the mean metal temperatures for these casts showed that the metal was only 90% saturated, the calculations made using the metal temperatures at the start of the casts showed that the carbon saturation percentage of the metal was then 98% (standard deviation = 0·5).

Silicon—The silicon content of basic pig iron for use in the open-hearth furnaces at the Steel Company of Wales is between 0·4% and 0·6%.

There is a considerable amount of operating skill involved in controlling the silicon content of pig iron and it is recognized by operators that factors increasing the heat available in the furnace (i.e. increase in coke rate and blast temperature) increase the silicon content of the metal.

A statistical examination of the data collected during the trial showed no significant correlation with the silicon content of the metal. The results obtained are shown below:

Metal Silicon versus:	Correlation Coefficient, r	Significance
Metal temperature	− 0·1	Not significant
Flushing-slag temperature	+ 0·10	Not significant
Metal sulphur	+ 0·01	Not significant
Blast temperature	− 0·14	Not significant
(S)/[S]*	− 0·03	Not significant
Coke rate	0·15	Not significant
Basicity	0·02	Not significant

A change in blast temperature is frequently made in an attempt to alter the silicon content of the metal. No significant correlation between the change in blast temperature between casts and change in metal silicon between casts was obtained, the correlation coefficient being 0·11.

The reasons for the absence of significant correlations with metal silicon remain somewhat obscure. The absence of any significant correlation of metal silicon with slag or metal temperature is probably due to the highly endothermic nature of the reduction of silica by carbon:

$$SiO_2 \text{ (crystalline)} + 2C \text{ (graphite)} \rightarrow Si \text{ (in iron)} + 2CO$$
$$\Delta H = + 136{,}300 \text{ cal.}$$

If increased heat is available in the hearth, then the reduction of silica to silicon could act as a stabilizer to the hearth temperature, increasing the silicon content of the metal rather than the metal or slag temperatures.

The absence of any significant correlation with the coke rate could possibly be due to successful forecasting by the operator. It must be remembered that if the coke rate is decreased in anticipation of an increase in silicon content, and this change has the desired effect, then, from the mathematical viewpoint, there are two casts of identical silicon contents but different coke rates. If the alterations in coke rate (both up and down) are usually successful in controlling the metal silicon, then no significant correlation between coke rate and metal silicon would be found. The relative constancy of the metal silicon during the trial (mean silicon = 0·53, $\sigma = 0·20$) suggests that

* The conventional practice of placing round and square brackets round the symbols for components in slag and metal respectively has been followed.

the alterations in coke rate were, in the main, successful in controlling the silicon content.

No claim is made that a significant statistical relationship implies cause and effect, and another example of the need to consider statistical relationships in the light of operating practice is the significant correlation found between the blast temperature and the flushing-slag temperature. The results are shown below:

Correlation Coefficient, r	Regression Coefficient, b	Residual Standard Deviation, °C	% Variance Explained	
− 0·65	− 0·37	25	42	7·6

The negative sign of the correlation and regression coefficients indicates the apparently paradoxical relation that the higher the blast temperature is, the lower is the slag temperature. This, however, is probably due to the practice of increasing the blast temperatures when slag temperatures are falling.

Sulphur—It is the policy of the Steel Company of Wales to produce a pig iron with $< 0{\cdot}03\%$ sulphur. The maximum removal of the sulphurous impurities of the burden in the slag is dependent mainly on the use of slags having a high potential for absorbing sulphur, but, unless care is taken in the adjustment of the slag composition, difficulties in blast-furnace operation will result. The use of magnesian limestone to give a magnesia content between 7% and 12% in slags containing 15–20% Al_2O_3 enables slag basicities $(CaO + MgO)/(SiO_2 + Al_2O_3)$ of up to 1·3 to be obtained without difficult furnace operation.

Statistical examination of the data obtained during the trial showed that a number of variables were significantly correlated with the partition of sulphur between slag and metal.

Two values were calculated for each cast, the first for the roughing-slag sulphur and the second for the weighted average sulphur in the flushing slag and roughing slag. The latter value was obtained from the % sulphur and weights of the two slags. The results obtained are shown below:

	Correlation Coefficient, r	Regression Coefficient, b	% Explained	
Roughing (S)/[S]				
Variable				
CaO/SiO_2	0·60	128	37	5
$\frac{(CaO + MgO)}{(SiO_2 + Al_2O_3)}$	0·81	303	61	9
Metal temperature	0·35	0·39	26	3·4
Flushing-slag temperature	0·37	0·30	26	4
Roughing (MnO)/[Mn]	− 0·69	− 48·1	57	4
Weighted (S)/[S]				
Variable				
CaO/SiO_2	0·56	121	11	5
$\frac{(CaO + MgO)}{(SiO_2 + Al_2O_3)}$	0·80	298	53	9
Metal temperature	0·17	0·18	2	1·6 *N*
Flushing-slag temperature	0·25	0·19	7	2·4
Weighted (MnO)/[Mn]	− 0·70	− 53·8	50	9·2

(*N* signifies not significant, i.e. $t < 2{\cdot}0 > 0{\cdot}05$)

From these results it can be seen that increase in the partition of sulphur between slag and metal is associated with an increase in the basicity and metal and slag temperatures, and a decrease in the partition of manganese between slag and metal; for the weighted ratio the influence of temperature was not so pronounced.

The effect of basicity is of paramount importance. The CaO/SiO_2 ratio is not so satisfactory in accounting for variations in the sulphur partition as the basicity ratio $(CaO + MgO)/(SiO_2 + Al_2O_3)$ and this is due to the variations in the magnesia content of the slag during the trial.

An equation has been deduced statistically relating the sulphur partition to slag basicity and flushing-slag (F.S.) temperature:

$$\frac{S}{[S]} = 320\,\frac{(CaO + MgO)}{(SiO_2 + Al_2O_3)} + 0{\cdot}47\,(\text{F.S. temp.}) - 970.$$

The percentage explained is 85, the standard errors are 14·2 and 0·057 respectively, and σr is 11.

From this is can be seen that a change of 0·1 in the basicity ratio, for a given temperature, changes the sulphur partition by approximately 32, and for a given basicity a change of 50° C in the slag temperature changes the sulphur partition by 23.

Since it is almost impossible to obtain precise control of the temperatures of slag and metal, it is evident that fluctuations in temperature can be responsible for changes in the distribution of sulphur between slag and metal which are outside the control of the operator. The advantage of the measurement of slag and metal temperatures at every cast as a routine is therefore evident, and it has already been shown that during the trial period the Si percentage in the metal was not found to give an indication of the metal temperature.

The sulphur content of the metal is affected not only by the distribution between slag and metal but also by the sulphur load on the furnace. If the sulphur load on the furnace increases by 10% it would appear that the sulphur content of the slag and metal would increase by 10% (Brower and Larsen[3]) and the distribution ratio would remain unchanged. This should be valid for sulphur contents in the slag up to about 2·5–3·0%. Table I shows that 90% of the sulphur load on the furnace was contributed by the coke. The advantages of coke of constant sulphur content are therefore evident if iron of constant sulphur content is to be made. Although fluctuations in coke sulphur at Margam during the trial period were not excessive, fluctuations of the order of 9% from the mean are to be expected on 1 in 20 occasions.

Variations in the sulphur content of the iron due to variation in the sulphur load when making low-sulphur iron (e.g. 0·02% S) are less than on making iron of higher sulphur content. For example a 10% increase in the sulphur load (which can occur due to variation in coke sulphur), when making iron of nominal 0·02% S or 0·06% S content, would alter the sulphur content by 0·002% and 0·006% respectively, the former being negligible. Owing to the heterogeneous nature of the blast-furnace burden, fluctuations in slag composition, and hence in the basicity ratio, are to be expected. Operating with a slag of high basicity to give a large partition of sulphur between slag and metal tends to minimize variations in metal sulphur due to fluctuations in the slag composition. A change in the basicity ratio of 0·05 was found to alter the sulphur partition ratio by 15. This

will have an insignificant effect on the metal sulphur if the partition ratio is high (> 60) but would have an increasing effect as the partition ratio decreased. Fluctuations of slag temperature similarly have a lesser effect on the metal sulphur content when the partition ratio is high.

Manganese—The correct manganese content required in the pig iron depends on the steelmaking practice; at the Steel Company of Wales it is about 1·5%. There is seldom sufficient manganese present in the normal iron ores used and recourse has to be made to manganese ore and open-hearth slag additions. Manganese ore is expensive and methods of conserving manganese are therefore important.

Statistical examination of the results obtained during the trial showed that the partition of manganese between slag and metal was significantly correlated with the partition of sulphur (*see* Sulphur), a high sulphur partition being associated with a low partition of manganese. This can be expressed in the form of an equation:

$$(S)/[S] = 35\,[Mn]/(Mn) + 9 \quad (r = 0{\cdot}76, \sigma r = 3{\cdot}2)$$

which is in good agreement with that found by Douglass,[4] ($b = 41$), during a statistical study of blast-furnace data collected over 96 weeks from a plant on the N.E. coast of Great Britain. If one assumes that the line should pass through the origin then the equation would become:

$$(S)/[S] = 40[Mn]/(Mn)$$

and the agreement with the value found by Douglass becomes very close. This is also in agreement with data published by Grant, Dowding, and Murphy,[5] but is significantly different from the value found by Turkdogan,[6] ($b = 28$), from blast-furnace data. He quoted no details of the significance of his equation which passed through the origin. As only half the variation in manganese partition can be related to the partition of sulphur, it is not valid to use one ratio to calculate the other. Hacking and Shanahan[7] have recently discussed the influence of manganese on the desulphurization of pig iron and show how the partitions of sulphur and manganese are interrelated. Further examination showed the following significant correlation with manganese distribution:

	Correlation Coefficient, r	Regression Coefficient, b	% Explained	t
Roughing (MnO)/[Mn]				
Variable				
CaO/SiO_2	− 0·50	− 1·54	11	4
$CaO + MgO/SiO_2 + Al_2O_3$	− 0·53	− 2·9	16	4
Metal temperature	− 0·44	− 0·007	20	4
Flushing-slag temperature	0·25	0·003	11	2·3
Weighted (MnO)/[Mn]				
Variable				
CaO/SiO_2	− 0·42	− 1·11	4	3·2
$CaO + MgO/SiO_2 + Al_2O_3$	− 0·48	− 2·16	10	3·7
Flushing-slag temperature	0·45	0·004	20	4
Metal temperature	0·46	0·006	19	5

The results show that the partition of manganese between slag and metal is decreased by increasing the slag basicity and the advantages of operating at a high basicity are evident. The mean weighted ratio of (MnO)/[Mn] for the 3 periods was 0·99, 1·29, and 0·89 respectively. This indicates how the loss of manganese in the slag increased during period 2 when the slag basicity was reduced from the normal. A similar relationship between slag basicity and manganese distribution has been observed in ferromanganese practice.[8] The influence of temperature is not clear. The partition of manganese between roughing slag and metal is decreased by an increase in metal temperature and increased by an increase in flushing-slag temperature. The (MnO)/[Mn] ratio calculated from flushing and roughing slags (weighted ratio) is increased by an increase in both metal and flushing-slag temperatures. Theoretically one would expect high temperatures to reduce the partition of manganese between slag and metal.

Phosphorus—Owing to the highly reducing conditions in the blast-furnace it is impossible to prevent all the phosphorus entering the metal. In order to keep the phosphorus content of the metal at the required value considerable manipulation of the burden composition is necessary when a large number of ores are being used in constantly varying amounts. The relative constancy of the metal phosphorus content during the trial period is shown in Table II for the three periods and indicates the success achieved.

Liquidus Properties of Blast-furnace Slags

It is essential for blast-furnace operation that the slag should be free-flowing at the temperatures prevailing in the hearth region. One of the most important conditions for a free-flowing slag is that no crystals should be present, i.e. the slag liquidus temperature should be lower than the slag temperature.

Considerable interest has been aroused by the publication by Osborn, De Vries, Gee, and Kraner[9] of liquidus diagrams for the four-oxide system CaO, MgO, SiO_2, Al_2O_3, which comprise over 95% of blast-furnace slag. In a series of graphs they were able to show the optimum slag composition for a given alumina content. At the optimum point the maximum desulphurization potential will be attained for a free-flowing slag. These optimum compositions are of particular assistance to plants operating with a high basicity ratio (i.e. $(CaO + MgO)/(SiO_2 + Al_2O_3) > 1$) in order to make low-sulphur pig iron.

The publication by Welch[10] of a simple method of measuring the liquidus temperatures gave the promise of a quick and accurate technique which could be applied to blast-furnace slags. Preliminary tests showed considerable promise and as a result a detailed study of the liquidus and high-temperature properties of blast-furnace slags has been made. Full details of the work will be published later.[11]

Samples of slags obtained during the trial were examined and the results obtained are shown below:

	Measured Liquidus Temp., ° C	Metal Temp., ° C	Roughing slag Temp. °C	Flushing Slag Temp., ° C
Period 1: Mean	1400	1420	1420	1505
Standard deviation	8	36	23	23
Period 2: Mean	1380	1420	1430	1525
Standard deviation	16	19	20	16
Period 3: Mean	1430	1435	1455	1530
Standard deviation	15	21	28	36

It can be seen that the liquidus temperature of the slag is 100–150° C less than the flushing-slag temperatures and between 20° and 50° C less than the roughing-slag temperatures. The change in liquidus temperature during the three periods is a result of the deliberate changes made in slag composition. The roughing slag which first appears during a cast is very viscous and it is not usual for roughing slag to flow freely until later. During the trial the first estimate of the roughing-slag temperature was made at the point at which the slag began to flow freely over the skimmer and down the slag runner. When the liquidus temperature of the slags from individual casts is compared with this first roughing-slag temperature, it is found that the roughing-slag temperature is on an average 15° C higher than the liquidus. This is in good agreement with the concept that slag viscosity increases below the liquidus point, and provides a practical confirmation of the assumption of Osborn *et al.*[9] that blast-furnace slags are free-flowing at temperatures above the liquidus and viscous at temperatures below the liquidus.

The highest $(CaO + MgO)/(SiO_2 + Al_2O_3)$ ratio reached during the trial (during period 3) was 1·2, and the cast results were:

Metal Analysis

C, %	Si, %	S, %	Mn, %	P, %	Temp., ° C
4·3	0·4	0·014	1·60	0·47	1420

Slag Analysis

SiO_2, %	CaO, %	MgO, %	Al_2O_3, %	Weighted S, %	Flushing Temp., ° C	Measured Liquidus Temp., ° C
29·7	41·6	11·9	14·8	1·4	1545	1460

It will be seen that the slag liquidus temperature was 85° C below the flushing-slag temperature and this ensured a free-flowing slag. The metal silicon content was not high and a (S)/[S] ratio of 100 was achieved. This particular slag composition is very near the optimum composition predicted by Osborn for working with 15% Al_2O_3 in the slag. It is important to obtain the correct magnesia content in the slag when operating at this high basicity. If the magnesia content had been 6%, with a corresponding increase of 6% in the lime to maintain a basicity of 1·2, then the liquidus temperature of the slag would have been about 1600° C.

Statistical examination of the relationship between slag basicity and liquidus temperature showed that it was not significant; this is, of course, not surprising, as it can be seen from the phase diagram that slags of a given basicity ratio can have a wide range of liquidus temperature.

Comparison of the measured liquidus temperature of the slag samples with that calculated from the Osborn diagrams, assuming the slag to be composed of CaO, MgO, SiO_2, and Al_2O_3 only, showed that the measured values lay, on the average, 15° C below the calculated values.

Herty Index of Blast-furnace Slags

No useful results were obtained by measuring the Herty Index of the slags. Despite the variations in slag composition and temperature no relationship with the index was found except during period 1, when a slight positive correlation of the index with the temperature was obtained. This is probably due to the fairly high basicity of the slags during the trial. The viscosity of such slags is low and only slightly influenced by change in temperature above the liquidus point. As an example, for the most basic slag used (basicity ratio 1·2), the viscosity changed from 3·2 to 1·9 poises between 1455° and 1555° C. It is not surprising that the Herty measurements, which are not very sensitive to small changes in viscosity, did not show any relationship between the index and the temperature. However, further measurements made on other plants operating with slags of greatly differing analysis may give useful information.

CONCLUSIONS

The trial has shown the necessity for the correct sampling of metal and slag if an accurate estimate of their analysis is required. Tests have shown that at least three samples should be taken to establish the analysis of any cast or flush. The iron sample must be cooled rapidly if an accurate analysis for carbon is required.

The difference found in the manganese and sulphur contents of roughing and flushing slag emphasizes the importance of sampling both slags. Any increase in the proportion of flushing slag to roughing slag would increase the removal of sulphur from the furnace in the slag and decrease the loss of manganese.

A sulphur balance of ingoing and outgoing materials showed that the coke contributed 90% of the sulphur load on the furnace, and hence variations in the sulphur content of the coke play a large part in causing variation in metal sulphur.

The underlying policy of the Steel Company of Wales is to manufacture pig iron with a low sulphur content and with low cast-to-cast variations. The trials have shown how this has been achieved by the use of slags of high basicity whose composition has been adjusted to give minimum liquidus temperatures. These conditions enable iron of low silicon as well as low sulphur content to be produced. Measurements made on the slag samples indicated that the liquidus temperature was always at least 85° C less than the slag temperature, thus ensuring free-flowing slags even at the highest basicities used.

It is hoped that similar investigations will be carried out on furnaces operating on other practices. Comparison of the results obtained with the present ones would enable further information on the influence of slag properties on metal composition to be obtained.

APPENDIX

In view of the variability of blast-furnace performance, it is necessary to apply simple statistical methods to the examination of relationships between the variables. In order to test the significance of an apparently linear relationship, the correlation coefficient (r) is calculated. This has characteristics such that, if the relationship between the data can be represented exactly by a straight line, then $r = \pm 1$, positive if the straight line has a positive slope and negative if the line has a negative slope. If there is no relation at all between the variables, then $r = 0$. The slope of the best straight line through the data is called the regression coefficient (b); this measures the

average increase in y per unit increase in x. It is important not only to test the significance of the coefficients but also to assess the utility of the equation deduced. For this purpose the factor '% explained' is calculated from $\frac{(1 - \sigma r^2)}{\sigma^2} \times 100$ where σ is the standard deviation of the variable and σr the standard deviation about the regression line. If this is not done it is possible to obtain significant correlations between two variables which are sometimes of very little value as only a very small part of the variations can be explained by the regression equation. The t value is a test of the significance of a correlation. For the majority of correlations studied it requires to be < 2 to have less than 5% probability of occurring by chance.

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Friction in Cold Rolling

By G. T. van Rooyen and W. A. Backofen

SYNOPSIS

Friction in the interface between roll and strip has been studied. Coefficient of friction along the arc of contact was determined using a special roll containing two small pins installed at right angles to the roll axis, one in a radial direction and the other inclined to the first in an oblique direction. Measurements were made of the stress along the axis of each pin as it travelled over the arc of contact. From the ratio of stress in the oblique and radial directions, a coefficient of friction could be computed as a function of position in the roll gap. Experiments were performed on aluminium strip with roll surfaces prepared by grinding and also by sand-blasting. Further information about friction over the contact arc was derived from the distortion of a fine grid machined on the strip surface prior to rolling. Over the range of conditions explored, evidence was found of sticking as well as variation in the friction coefficient along the arc of contact. 1350

Introduction

FRICTION IN THE INTERFACE between a rigid tool and material being plastically deformed by the tool is one of the more important considerations in both the theory and practice of plastic working processes. In an experimental study of the problem, it would be ideal to devise some means of exploring in reliable, point-by-point fashion, frictional conditions over such an interface. To date, that goal has not been realized, because of the complexities encountered even in relatively simple processes. Several procedures have been developed, however, for determining an average value of the interface friction coefficient, that are applicable to various processes and conditions of working.[1, 2, 3]

Most rolling theories take the friction coefficient to be constant along the arc of contact. The possibility of variation has always been realized but, owing to experimental difficulties associated with a point-by-point measurement, very little direct evidence is available. Some assumptions have been made about the variation of the friction coefficient along the arc of contact and have been included in theoretical treatments of the radial or normal pressure-distribution curves.[4, 5] In this connection, a mathematical investigation by Brown[6] is of interest.

To measure directly any variation in the friction coefficient along the contact arc in rolling, it is necessary to know the normal pressure and the tangential, or friction-induced, shear stress at each point, the ratio of the latter to the former yielding a value of friction coefficient. Normal pressure directed along the roll radius can be measured by what might be

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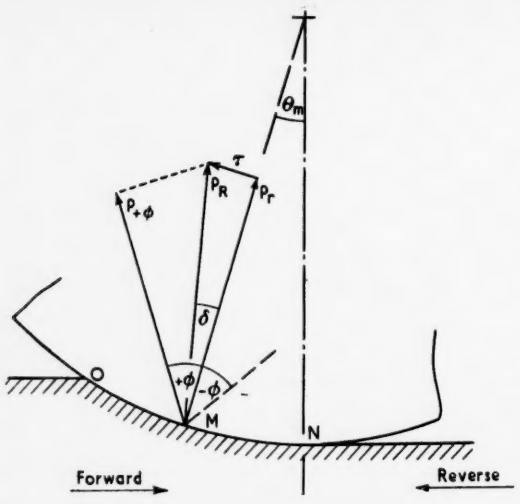


Fig. 1—Location of pins in roll

called the pressure-sensitive pin technique. A small weighbar or pin, fitted radially into the roll and ending flush with the roll surface, makes contact with some type of pressure transducer which provides a measure of the load on the pin as metal is rolled. This technique was first used in 1933 by Siebel and Lueg[7] for the determination of normal pressure distribution along the arc of contact. It has been used by Astakov,[8] Smith, Scott, and Sylwestrowicz,[9] MacGregor and Palme,[10] Bergen and Scott,[11] and Parish,[12] in other rolling studies involving metals, plastics, and textiles. It has also been used by Tompsen and Frisch[13] and Duwez and Zwell[14] in studies of the die-wall pressures in extrusion and metal-powder pressing, respectively.

The major aim of the present work was the measurement of tangential as well as normal stress to determine the friction coefficient along the entire arc of contact. The procedure developed made use of two pins, that for normal pressure measurement being installed in a radial direction, and the oblique pin being inclined in the rolling direction at an angle ϕ° to the radial pin. Figure 1 illustrates schematically the intended function of the pins and the important symbols are listed as follows:

σ = radial or normal stress between rolls and strip at any point M
τ = friction-induced shear stress on the surface at any point M
p_r = stress in radial pin
$p_{+\phi}$ = stress in oblique pin inclined at an angle $+\phi^\circ$ measured from the radial direction towards the entrance point O
$p_{-\phi}$ = stress in oblique pin inclined at an angle $-\phi^\circ$ measured from the radial direction towards the exit point N such that $|+\phi^\circ| = |-\phi^\circ|$
μ = coefficient of friction between strip and roll; $\mu = \tau/\sigma$
σ_Y^* = yield stress of the strip in plane-strain compression
τ_Y^* = yield stress in shear, $\sigma_Y^*/2$
A = cross-sectional area of pins

Basis of Measurement

Determination of p_r and $p_{+\phi}$ with radial and oblique pins respectively can be translated into a value of μ. Since

$$p_r A = \sigma A$$

$$p_{+\phi} A = \sigma \frac{A}{\cos\phi} \cos\phi + \tau \frac{A}{\cos\phi} \sin\phi$$

$$\frac{p_{+\phi}}{p_r} = 1 + \mu \tan\phi$$

therefore

$$\mu = (p_{+\phi}/p_r - 1) \cot\phi.$$

The friction coefficient is thus a function of the ratio of the stress in the oblique pin to that in the radial pin. The above equation is based on the assumption that there is no interference with pin response by friction between the pins and the roll in which they are installed ($p_r = \sigma$); Appendix I contains the expression providing for the effect of such friction, which must exist. Since the surface shear stress changes direction at the neutral point, the oblique pin, inclined at the angle $+\phi^\circ$ as shown in Fig. 1, will become subjected to a heavy side load on the exit side of the neutral point, and for this reason its response might well be suspected. The exit side could then be explored with another oblique pin inclined at the angle $-\phi^\circ$. However, the oblique pin inclined at $+\phi^\circ$ can still be used for this region of the contact arc by rolling in the reverse direction as shown in Fig. 1.

A matter of importance is brought out by the previous equation when reasonable values of μ and ϕ are substituted. Taking $\mu = 0{\cdot}2$ and $\phi = 26^\circ\,34'$ for the purpose of illustration, it will be found that an error of 1% in either p_ϕ or p_r leads to an error of 10% in the resulting friction coefficient. An awareness of the precision of measurement is, therefore, of much concern in establishing the reliability of μ values so determined.

In an effort to obtain additional information supporting the principal results, another experimental approach was made to the study of friction in the roll gap. This involved the measurement along the contact arc, on a partially rolled strip, of the separation

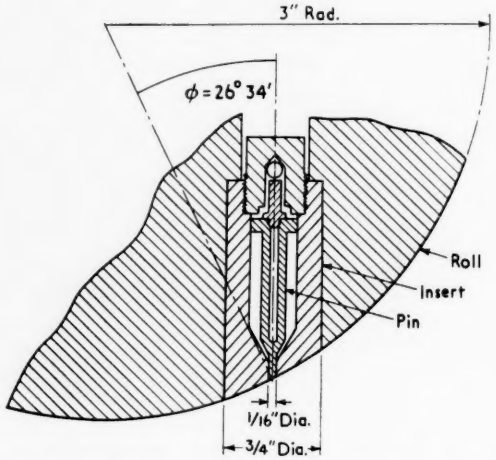


Fig. 2—Cross-sectional view of oblique pin

between fine reference marks, machined initially with equal spacing at right angles to the rolling direction. From the spacing of adjacent marks, any zone of sticking between strip and roll will immediately be revealed by the spacing remaining constant.[15, 16] Apart from defining a zone of sticking, the spacing should also have some qualitative value in revealing differences in frictional conditions in the roll/strip interface.

EXPERIMENTAL PROCEDURES

Apparatus and Materials

Experiments were carried out in a two-high mill with hardened steel rolls of 6-in. diameter and 10-in. length at a rolling speed of 25 ft/min. The material for all tests was 2S–18H aluminium. Specimen strips measured 2 in. × 9 in. × $\frac{1}{4}$ in. thick. Since the ratio of strip width to thickness was initially 8, there was some departure from the condition of plane strain. Reduction in rolling was fixed at 50%, while the roll surface preparation was varied to change frictional conditions. To explore the friction coefficient on the entrance as well as the exit side of the neutral point, tests were made by rolling in both the forward and reverse directions (Fig. 1). With a 50% reduction, the horizontal projection of the contact arc was approximately $\frac{5}{8}$ in., or about 10 times the diameter of the pins at the roll surface. Smith, Scott, and Sylwestrowicz[9] have shown that, with such geometry, pressure correction for the finite size of the pin is less than 2%, except at the roll-gap entrance and exit, and the neutral point.

Roll surface preparation consisted of grinding to R.M.S. roughness 11 μin. and also sand-blasting to a uniform mat finish of R.M.S. roughness 60 μin. Surfaces of the specimens were prepared by etching in a 5% NaOH solution to produce a uniform mat finish. Similarly, the roll surface after each pass was sponged with a 5% NaOH solution to dissolve any aluminium transferred in rolling. Finally the roll surface was washed and cleaned with carbon tetrachloride.

Strain-hardening characteristics of the aluminium were determined with small tensile bars machined so that the gauge length was in the rolling direction. A certain amount of anisotropy was found to be present, since the minimum section of the neck became elliptical with the minor diameter in the strip-thickness direction.

A cross-sectional view of the experimental roll, showing only the oblique pin, is presented in Fig. 2. Including the radially mounted pin would only have complicated the drawing. Both pins were installed in the lower roll so that they terminated at the roll surface, with their centres spaced $\frac{7}{8}$ in. apart on the same line parallel to the roll axis. The diameter of the tip making contact with the strip was $\frac{1}{16}$ in. Each hardened steel pin was fitted into the roll so that, when the pin was in position, the tip protruded through the insert at the front. The back end of the pin had a round boss which was ground concentric with the pin and which guided the pin in the insert at the back. To prevent binding with minimum clearance between pin-tip and insert, both pin and insert were finally lapped to give a high-precision fit. The diametral clearance between the tip of the pin and the insert where contact is made with the strip was about 0·0002 in. The angle ϕ between the radial and the oblique pin was made to be 26° 34′, so that $\tan \phi = 0{\cdot}5$.

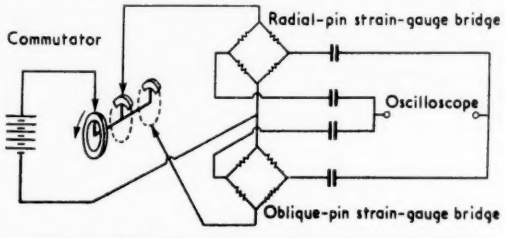


Fig. 3—Schematic layout of electrical circuit

Electrical strain gauges, SR–4, C–7, and C–8, were mounted on the square body of the pin to form a Wheatstone bridge circuit which provided compensation for both temperature variations and any bending stresses imposed on the pin. A schematic diagram of the electrical apparatus used for recording outputs from the strain-gauge bridges of the two pins is shown in Fig. 3. The d.c. supply voltage to the two weigh-bars was chopped by a rotary commutator fitted with silver contacts. A complete cycle of chopping consisted of applying a d.c. voltage to the radial-pin gauges in $\frac{1}{3}$ of the cycle, applying a d.c. voltage to the oblique-pin gauges in the next $\frac{1}{3}$, and then isolating the gauges of both pins so that no output from either was obtained for the remaining $\frac{1}{3}$ of the cycle. Thus it was possible to obtain both signal traces as well as a zero line on the oscilloscope screen. This had an advantage over recording each signal separately in that both signals were amplified by one amplifier and recorded on the same screen. Both signals will therefore be subjected to the same distortion, non-linearity, etc. that may be present in the electronic and recording equipment. The ratio of the two signals could then be determined at all times very accurately and almost independently of inaccuracies in the electronic system. The two signals which appeared as a series of dots on the oscilloscope screen were photographed with a Land Polaroid camera.

The same rolling conditions were used in studying the behaviour of reference marks on the strip surface. After the initial etching, a specimen was mounted off-centre in a lathe and a series of parallel scratches about 0·004 in. deep, $\frac{1}{8}$ in. long, and spaced 0·019 in. apart, was machined along the centre line with a sharp-pointed tool mounted on a boring bar. The distance between consecutive scratch marks along the contact arc of a partially rolled specimen was finally measured with a travelling microscope, providing accuracy of measurement of about 0·5%.

Calibration Procedure

In general, both pins will be subjected to side load acting between pin and insert. With $\phi = 26° 34'$ ($\tan \phi = 0{\cdot}5$) and assuming no shear stress at the roll surface ($\mu = 0$), a pressure of σ lb/in^2 directed along the roll radius will result in a force of $\sigma \times A$ lb along the oblique-pin axis and a side load perpendicular to the oblique-pin axis of $\sigma \times A \tan \phi$ lb, which is half the axial load. For a more realistic case, it is possible

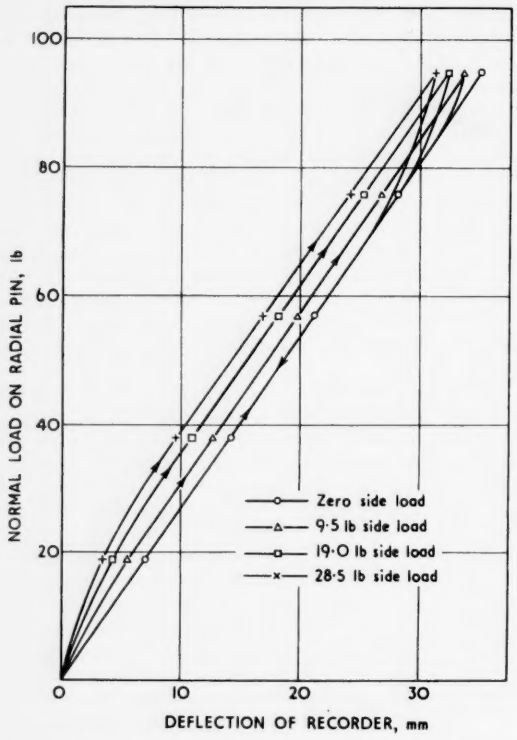


Fig. 4—Calibration of radial pin in insert with normal and side loads

to show that when $\mu = 0{\cdot}25$ both the radial and oblique pins will experience the same side load. Also, if $\mu = 0{\cdot}5$, there will be side load only on the radial pin.

Because the pins are subjected to variable side loading, it was necessary to establish a value for the friction coefficient between the pins and the walls of the inserts where they bear. Accordingly, the two pins were calibrated in the inserts with a series of increasing and decreasing normal loads, accompanied by different side loads, applied to the pins protruding from the inserts before being ground flush. In all respects the two weighbars responded identically. Figure 4 shows such a series of calibration curves for the radial pin with various constant side loads plotted so that the unloading curve is coincident in all cases. A calibration test for both pins was also made, after grinding the pins flush with the insert and roll surface, by applying load directed along the roll radius. A yoke from which weights were suspended was used for this purpose, with the load being transmitted from the yoke through a small projection set on the pin flush with the roll surface. The result for the oblique pin was such that, as the radially directed load on the pin increased, the pin was subjected not only to an increased axial load but also to an increased side load which was always half the axial load ($\phi = 26° 34'$). This second type of calibration was repeated for both pins before and after each strip was rolled. For convenience, it was done with a Baldwin SR–4 strain indicator. Successive calibrations of the oblique and radial pin without exception were reproducible within $\pm 1\%$. Such a finding was taken to mean that the friction coefficient between the pin and insert could be established with reasonable confidence.

Figure 5 shows a typical calibration of the last-mentioned type for the oblique pin. It is seen that both loading and unloading curves become straight lines after sufficient application or removal of the radially directed load. With the treatment described in Appendix II, a value for the friction coefficient μ_o, between pin and insert, of 0·155 was deduced for the straight-line loading and unloading paths in Fig. 5. Reference to Appendix II also shows how calibration tests on the radial pin (Fig. 4) substantiated the value of μ_o; points *xx*, *yy*, and *zz* in Fig. 5 were determined in this manner from Fig. 4 for the conditions of Fig. 5.

The calibration of the radial pin in the roll after a number of tests showed that loading and unloading followed the same straight-line path, suggesting negligible binding of the pin in the insert. The same remark applies to the oblique pin, since μ_o, determined in calibration testing, remained unchanged even after rolling a large number of strips. Furthermore, when the two weighbars were finally removed, there were no visible signs of metal having been extruded up into the annular space between the pins and inserts, which would be expected to be a source of some binding action. However, the possibility cannot as yet be

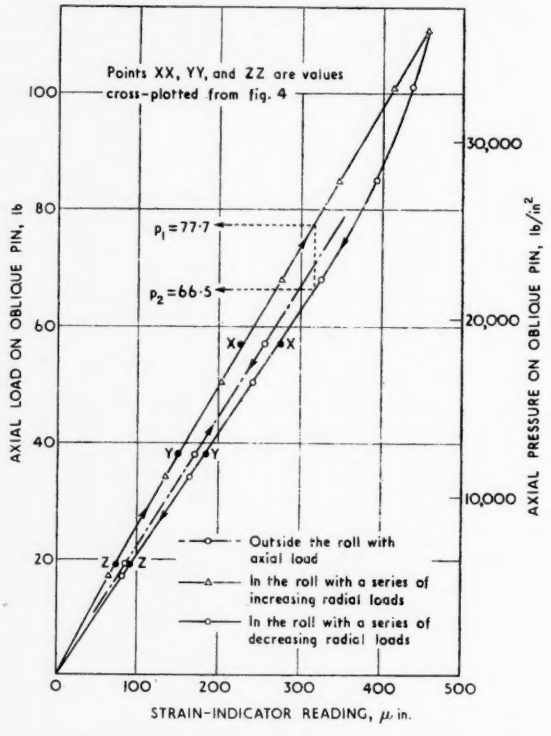
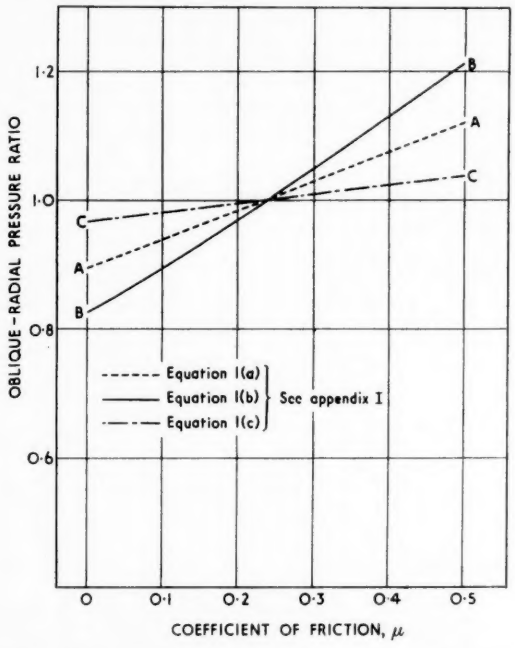

Points XX, YY, and ZZ are values cross-plotted from fig. 4
$p_1 = 77{\cdot}7$
$p_2 = 66{\cdot}5$
AXIAL LOAD ON OBLIQUE PIN, lb
AXIAL PRESSURE ON OBLIQUE PIN, lb/in²
STRAIN-INDICATOR READING, μ in.
Outside the roll with axial load
In the roll with a series of increasing radial loads
In the roll with a series of decreasing radial loads

Fig. 5—Calibration of oblique pin in roll with a radial load

ruled out entirely that some binding might have occurred while the system was under load in the roll gap. Indeed, when a specimen with two longitudinal grooves machined along its length was rolled so that the two pins did not contact the strip, it was found that the elastic distortion of the roll caused forces to be impressed on the pins which amounted to about 5–10% of the values obtained when the pins did make contact. The same finding has been reported by Smith, Scott, and Sylwestrowicz.[9] The record obtained in grooved-strip rolling was similar for the two pins, so that the ratio of the stress in the oblique pin to that in the radial pin, and consequently the experimentally determined value of μ, is not likely to be greatly affected by whatever causes this response.

Friction Between Pin and Insert

Friction between pin and insert can influence the forces recorded during rolling in a number of ways. Recorded forces will be equal to the forces exerted by the strip only if there is no relative motion between pin and insert, or when the pin and insert are equally stiff. In general, however, that is not the case and movement between pin and insert under load, although very small, will occur with an attendant influence on the forces recorded. On approaching the neutral point, for example, when the pins are experiencing increasing pressure, recorded values will be lower or higher than actual values, depending upon whether the pins are less or more stiff than the insert. On the exit side of the neutral point, where pressure is decreasing, the opposite will hold; namely, the recorded forces will be greater than the forces exerted by the strip if the pins are less stiff than the inserts, and vice versa. The net effects of such possibilities on the determination of the friction coefficient have been calculated and are presented in Appendix I.



Relationships between the measured pressure ratio and μ, under increasing pressure, for the different assumptions relative to stiffness of pin and insert.

Curve *A*: Equal stiffness with no relative movement between pin and insert.

Curve *B*: Pin less stiff than insert with friction between pin and insert causing artificially low measured pressure.

Curve *C*: Pin more stiff than insert with friction between pin and insert causing artificially high measured pressure.

Fig. 6—Correction curves for friction

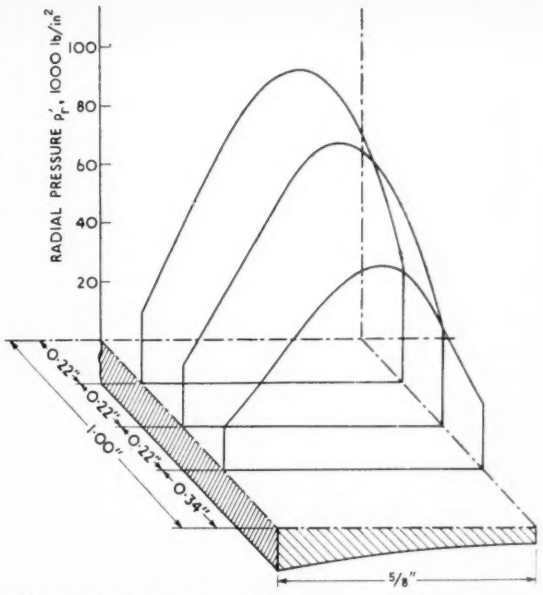


Fig. 7—Radial pressure distribution at different points in the roll gap with the sand-blasted roll

Equations 1(*a*), 1(*b*), and 1(*c*) of Appendix I relate $\mu = \tau/\sigma$ with p_ϕ/p_r, p_ϕ'/p_r', and p_ϕ''/p_r''. Equation 1(*a*) applies when pin and insert are equally stiff so that no relative movement takes place ($\sigma = p_r$). The ratio p_ϕ'/p_r' from equation 1(*b*) applies in the case of increasing forces when the pins are less stiff than

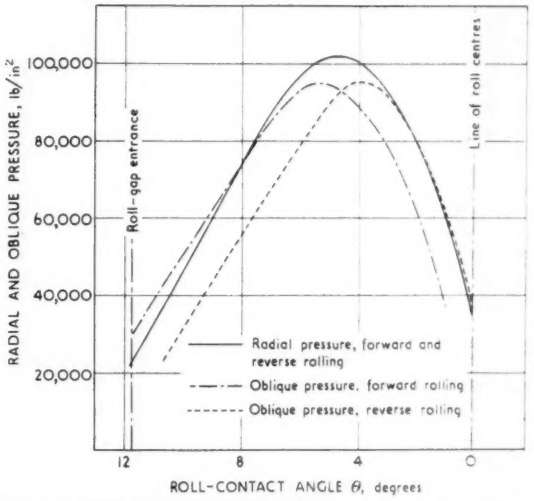


Fig. 8—Typical test results for forward and reverse rolling with sand-blasted roll

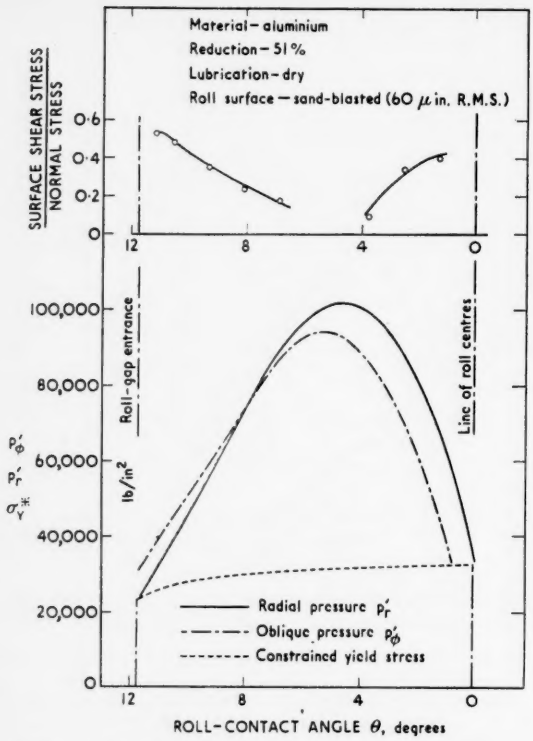


Fig. 9—Ratio of surface shear stress to normal stress with sand-blasted roll

the insert, while p_ϕ''/p_r'' from equation 1(*c*) relates to increasing forces when the pins are stiffer than the insert. The three equations are represented graphically in Fig. 6.

In determining friction coefficient from the force records, it was assumed that the pins were less stiff than the inserts in the roll (equation 1(*b*)). This assumption was made in spite of the fact that both pins left an impression on the rolled strip about 0·0003 in. deep. Such a finding might be interpreted to mean that the pin–insert stiffness relationship is the reverse of that assumed. However, that interpretation was rejected for two reasons: firstly, some pin protrusion seems almost unavoidable, since just as the pin leaves the contact arc a portion of the insert is still under load, which could cause it to be depressed to a level below the tip of the pin. The other reason, presented below, derives from the much more logical results obtained by interpreting the data in terms of a pin less stiff than the insert.

EXPERIMENTAL RESULTS

Oblique-Radial Pin Technique

During a test the two pins simultaneously make contact at points $\frac{7}{16}$ in. on either side of the centre-line of the strip. Since the condition of plane strain is not entirely fulfilled, the pins are not subjected to the maximum pressures which will exist along the centre line. Figure 7 gives a three-dimensional graph of the radial or normal pressure distribution as a function of position in the roll gap for three different points across the width of the strip. With Fig. 7 as a guide, it is estimated that the measured normal stress p_r' is about 90% of the maximum.

A typical test result plotted in Fig. 8 for the sand-blasted roll surface shows the variation through the roll gap of the experimentally determined p_r' and p_ϕ', for both forward and reverse rolling; the superscript now signifies, as noted above, that the measurements reflect the action of a pin less stiff than the insert. In all cases, records of force variation were reproducible within $\pm 5\%$ for strips rolled under identical conditions. The ratio p_ϕ'/p_r', however, was always much more closely reproducible.

No attempt was made to establish experimentally the exact point of entrance to the roll gap or the location of the curves with respect to the line joining roll centres. On the abscissa representing the contact angle, the entrance point was taken as the point of maximum curvature on the radial pressure distribution curve. This point always lies within half the pin diameter from the beginning of the record for the radial pin. The exit point is more difficult to define since it is influenced appreciably by roll-flattening and elastic recovery of the strip; it was located where the radial-pin stress equalled the yield stress of the strip at the appropriate reduction.

Figures 9 and 10 contain results obtained with the sand-blasted as well as ground roll surface under

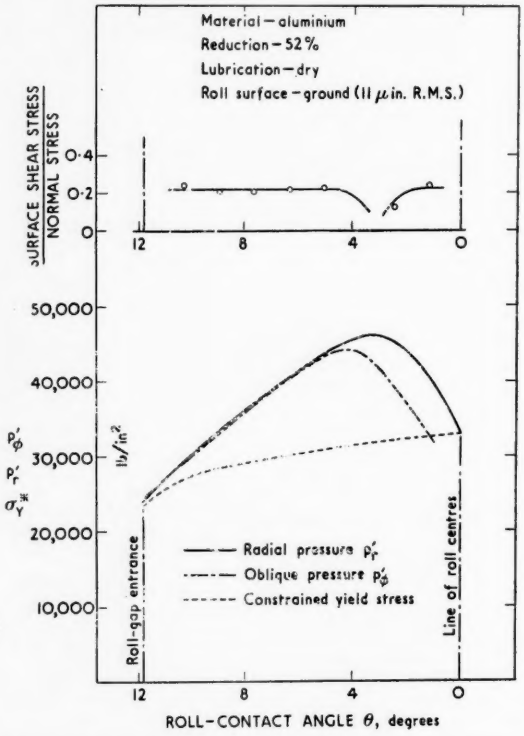


Fig. 10—Ratio of surface shear stress to normal stress with ground roll and no lubrication

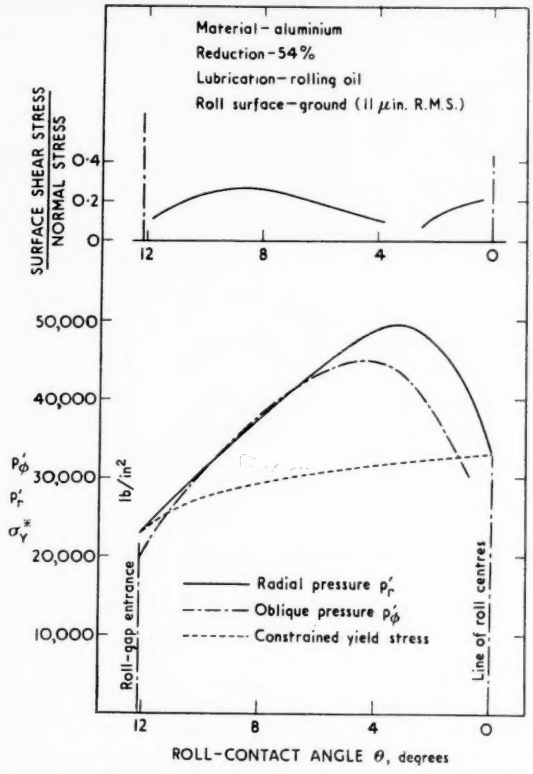


Fig. 11—Ratio of surface shear stress to normal stress with ground roll and oil

dry rolling conditions. Figure 11 contains the results obtained with the ground roll using a proprietary oil as lubricant. In each case the solid curve represents the variation in radial-pin stress, while the chain line gives the oblique-pin stress for forward rolling. Also included is the variation in the constrained yield stress and the ratio of the surface shear stress to radial or normal stress through the roll gap. The constrained yield stress was established in a very approximate way by increasing the yield stress found in tension testing by only 10%, since it was apparent that the condition of plane strain was not entirely fulfilled.

The ratio of surface shear stress to normal stress, or the friction coefficient when sliding takes place, was obtained as outlined previously, allowing for friction between pins and inserts on the basis of the pins being less stiff than the inserts in the roll. The portion of the curve describing the ratio of shear stress to normal stress on the exit side of the neutral point was determined from curves obtained from reverse rolling, using a friction-correction curve similar to that in Fig. 6 for decreasing forces with the pins less stiff than the inserts in the roll.

Reference Marks

Figures 12 and 13 summarize the measurements of spacing between consecutive marks along the arc of contact of partially rolled strips. Also included in these graphs is the calculated spacing of consecutive marks assuming homogeneous compression in the roll gap. The horizontal lines on the entrance and exit sides of the roll gap are the average spacings between large numbers of reference marks before and after rolling. In all cases, creep took place in the

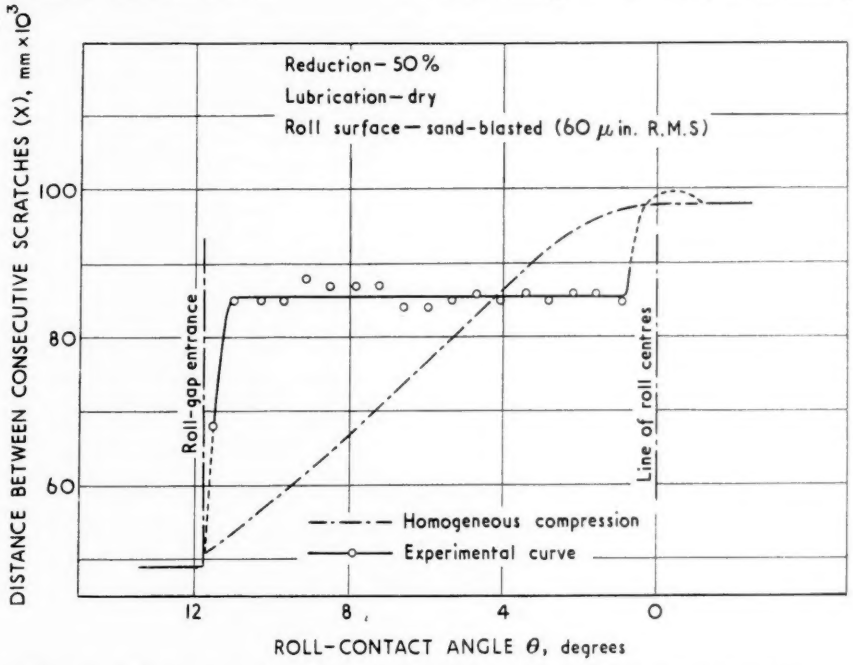


Fig. 12—Reference mark spacing on strip rolled with sand-blasted roll surface

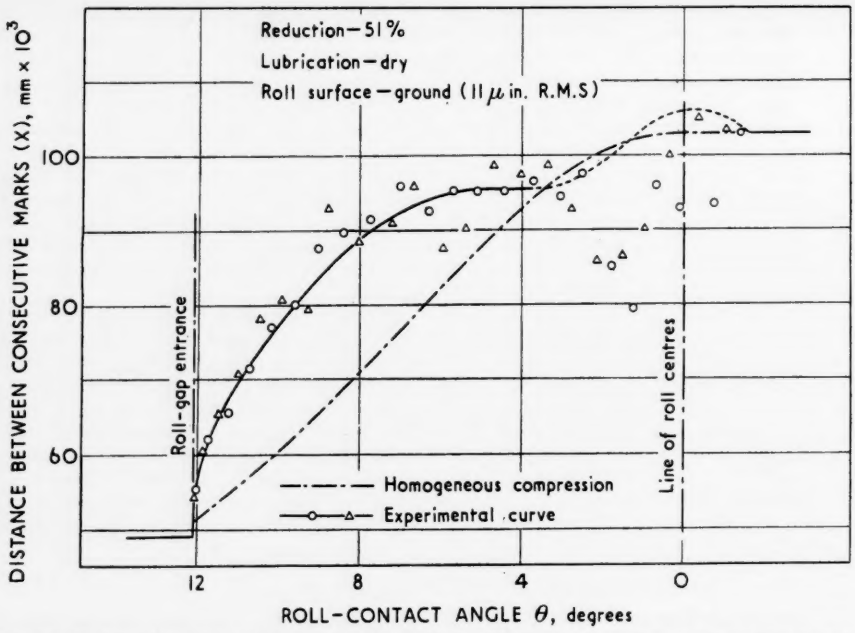


Fig. 13—Reference mark spacing on strip rolled with ground surface and no lubrication

strip during the interval after the mill had stopped and before the roll could be lifted. Such creep is reflected in the curves by the lengths of the measured contact arcs being slightly greater than the calculated arc lengths; a small amount of this discrepancy could also have been due to roll-flattening. Creep could only have been important in the region of the line joining roll centres where it tended to cause the spacing to pass through a maximum.

DISCUSSION OF RESULTS

The results obtained are the first of this type known to the authors, so that is difficult at present to subject them to an independent quantitative check. Of special interest is the decrease in the ratio of surface shear stress to normal stress in Fig. 9, for the sand-blasted rolls, from a value of about 0·4 at the entrance to zero at the neutral point. The gradually decreasing value suggests that sticking to the roll surface must have occurred over an appreciable part of the contact arc in accordance with the criterion[17] that sticking takes place when $\mu p_r = \tau_Y^*$ or $\mu \geqslant \sigma_Y^*/2p_r$.

Sticking when rolling with the sand-blasted roll is confirmed by the reference mark measurements of Fig.12 which show the spacing to remain remarkably constant over most of the contact arc. When the measured value of surface shear stress through the roll gap was compared with τ_Y^* obtained by tension testing, agreement was within the experimental accuracy. This finding also supports the assumption that the pin is less stiff than the insert; if the converse is assumed, the shear stress calculated with equation 1(*c*) is greater than the yield stress at the entrance point and decreases to zero before the neutral point is reached.

The ratio of shear to normal stress plotted in Fig. 10 for rolling with the smoother, ground surface is essentially constant over the greater portion of the entrance side of the contact arc, suggesting slipping between strip and roll with a friction coefficient of $\mu = 0{\cdot}1$; a comparable value has been reported from other work on the dry rolling of aluminium. The decrease to zero at the neutral point may indicate a small zone of sticking. The size of the pins is also important, as the overall effect of allowing for the finite size of the pin will be to make the curve decrease to zero much more abruptly. Data plotted in Fig. 13 show a large deviation from the condition of homogeneous compression, and so, qualitatively indicate a fairly high friction coefficient. In the vicinity of the neutral point, there is a region where very little, if any, slipping over the roll surface could have occurred. Experimental points in this region, however, show considerable scatter and no definite conclusion can be reached. The scatter was not due to inaccuracies in measurement but rather to some type of limiting lubrication which was continually breaking down, with sticking and slipping taking place alternately on a near microscopic scale. The resultant wavy appearance shown in Fig. 14*a* of the reference scratches appearing in this region of the contact arc suggests such behaviour. By way of contrast, Fig. 14*b* shows a perfectly straight reference scratch photographed in approximately the same location for the case of rolling with the sand-blasted rolls when sticking must have occurred.

Sources of Error

The usefulness of the oblique-radial pin technique for studying tool/metal interface friction is clearly limited by the accuracy and reliability with which

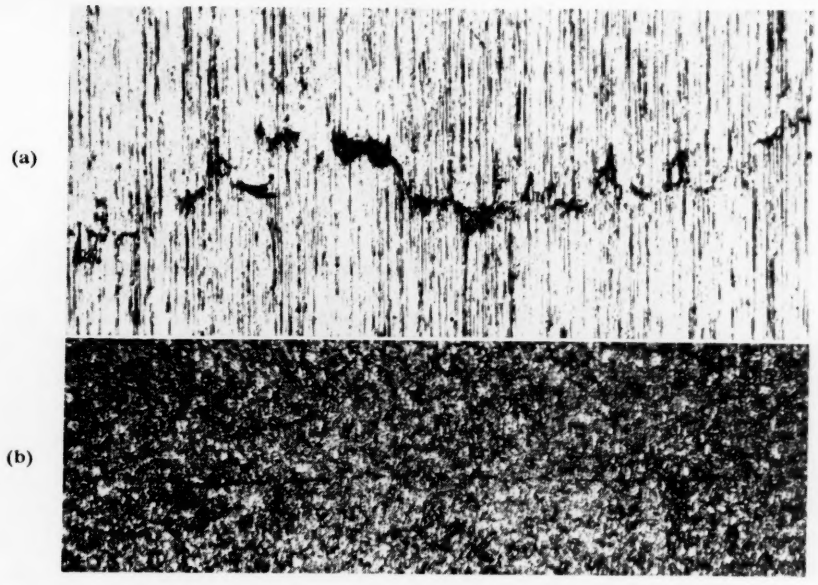


Fig. 14—Scratch mark in the vicinity of the neutral point using no lubricant with (*a*) a ground roll surface (R.M.S. roughness: 11 micro-in.) and (*b*) a sand-blasted roll surface (R.M.S. roughness: 60 micro-in.) × 50

measurements can be made. The fundamental behaviour of pins for measuring pressure between roll and strip, therefore, is an especially important consideration. Amongst the possible sources of error in the treatment of such measurements may be listed:

(i) The assumption that normal and shear stresses present at each of the two points where pins simultaneously make contact with the strip are the same, so that a ratio may be formulated with measurements made at the two different locations.

(ii) The method of allowing for friction between pin and insert. Some limitation certainly must exist. As seen from the calibration curve in Fig. 3 for the oblique pin in the roll, the friction coefficient becomes constant with either steadily increasing or decreasing load. However, as the load begins to decrease from the maximum, hysteresis is found, which obviously makes any correction very difficult. Such a situation must exist in the vicinity of the neutral point. Furthermore, the friction coefficient μ_0 might well depend on the difference in stiffness between pin and insert.

(iii) The assumption that the pin is less stiff than the insert. The allowance made for friction between pin and insert hinged upon this assumption, which is supported by the nature of the experimental results. It is acknowledged, however, that no absolute proof is available.

(iv) The possibility of binding between pin and insert owing to elastic distortion of the roll as a strip passes through the roll gap

(v) Protrusion or recession of the pin relative to the surface of the insert. Although Smith, Scott, and Sylwestrowicz have shown that protrusion of 4% of the pin diameter has an effect of less than 3% on the integrated radial pressure distribution, it is felt that such protrusion could have a more marked effect on the values of friction coefficient measured with the oblique-radial technique. It is anticipated that the variation in oblique-pin stress will be especially sensitive to small amounts of protrusion or recession.

In view of these sources of error, it is difficult to attempt even a rough approximation of the precision with which μ has been measured in the present work. Results were sufficiently encouraging, however, to justify the further work that is now being carried out with the aim of simplifying the technique and improving the over-all accuracy of measurement.

SUMMARY AND CONCLUSIONS

Both the radial-oblique pin and the surface reference-marker techniques were found to be useful tools for exploring frictional conditions along the arc of contact. A high accuracy of measurement was found to be necessary in the use of the oblique and radial pins and the behaviour of pins for measuring pressure between roll and strip was considered in some detail. In particular, the influence of friction between pin and roll (or insert) as affected by their relative stiffnesses has been examined. Although the present techniques have not been refined to such an extent that they allow highly accurate measurements of friction coefficient, it is felt that they have great potential and with refinement will yield results of greater precision.

APPENDIX I

Equations for μ Allowing for Friction Between Pins and Inserts (*see* Fig. 15)

(*a*) *Pins and Inserts of Equal Stiffness, or* $\mu_0 = 0$

$$p_r A = \sigma A$$

$$p_\phi A = \sigma \frac{A}{\cos \phi} \cos \phi + \tau \frac{A}{\cos \phi} \sin \phi$$

and

$$\frac{p_\phi}{p_r} = (1 + \frac{\tau}{\sigma} \tan \phi)$$

Therefore

$$\frac{\tau}{\sigma} = \mu = \left\{ \frac{p_\phi}{p_r} - 1 \right\} \cot \phi$$

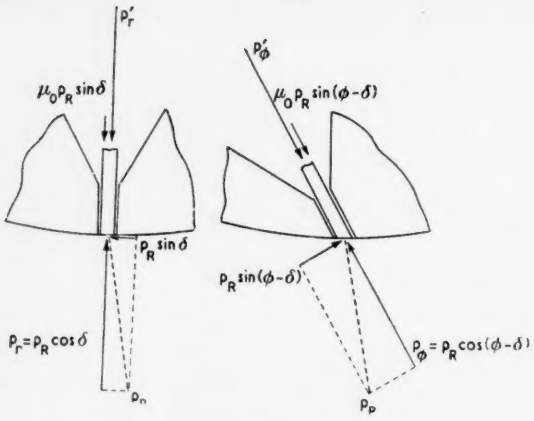


Fig. 15—Stresses acting on pins

if $\phi = 26° 34'$

$$\mu = 2{\cdot}00\left\{\frac{p_\phi}{p_r} - 1\right\} \quad \ldots\ldots\ldots\ldots 1(a)$$

(b) Pins Acting Less Stiff than Inserts

For forward rolling on the entrance side of the neutral point, the relative motion between pins and inserts will be such that

$$p_r' A = p_r A - \mu_0 \tau A$$
$$p_r' = \sigma - \mu_0 \times \tau$$

while

$$p_\phi' A = p_\phi A - \mu_0(\sigma A \tan\phi - \tau A)$$
$$p_\phi' = \sigma + \tau\tan\phi - \mu_0(\sigma\tan\phi - \tau)$$

so that

$$\frac{p_\phi'}{p_r'} = \frac{1 + \mu\tan\phi - \mu_0\tan\phi + \mu\mu_0}{1 - \mu\mu_0}$$

f

$$\phi = 26° 34' \text{ and } \mu_0 = 0{\cdot}155$$
$$\frac{p_\phi'}{p_r'} = \frac{0{\cdot}923 + 0{\cdot}655\mu}{1 - 0{\cdot}155\mu} \quad \ldots\ldots\ldots 1(b)$$

(c) Pins Acting More Stiff than Inserts

For forward rolling on the entrance side of the neutral point, the relative motion between pins and inserts will be such that (replacing superscript ′ by ″)

$$p_r'' A = p_r A + \mu_0 \tau A$$
$$p_r'' = \sigma + \mu_0 \tau$$

while

$$p_\phi'' A = p_\phi A + \mu_0(\sigma A \tan\phi - \tau A)$$
$$p_\phi'' = \sigma + \tau\tan\phi + \mu_0(\sigma\tan\phi - \tau)$$

so that

$$\frac{p_\phi''}{p_r''} = \frac{1 + \mu\tan\phi + \mu_0\tan\phi - \mu\mu_0}{1 + \mu\mu_0}$$

if

$$\phi = 26° 34' \text{ and } \mu_0 = 0{\cdot}155$$
$$\frac{p_\phi''}{p_r''} = \frac{1{\cdot}078 + 0{\cdot}35\mu}{1 + 0{\cdot}155\mu} \quad \ldots\ldots\ldots\ldots 1(c)$$

APPENDIX II

Calculation of Friction Coefficient μ_0

Consider the oblique pin acted upon by a load of $P/\cos\phi$ directed along the roll radius. Then the axial load on the pin is P and the side load is $P\tan\phi$. In the absence of any friction between pin and insert, let the axial strain recorded with the strain-gauge bridge on the pin be d. Now suppose that, with friction acting between pin and insert, radial loads $p_1/\cos\phi$ and $P_2/\cos\phi$ are required to give the same strain d in the pin on loading and unloading, respectively.

Then on loading

$$P_1 - \mu_0 P_1 \tan\phi = P$$

while on unloading

$$P_2 + \mu_0 P_2 \tan\phi = P$$

Therefore

$$P_1 - P_2 = \mu_0 \tan\phi(P_1 + P_2)$$

and

$$\mu_0 = \frac{(P_1 - P_2)}{\tan\phi(P_1 + P_2)}$$

If

$$\phi = 26° 34' \text{ and } \tan\phi = 0{\cdot}5$$
$$\mu_0 = \frac{2(P_1 - P_2)}{(P_1 + P_2)}$$

From Fig. 5 take

$$P_1 = 77{\cdot}7 \text{ lb}$$
$$P_2 = 66{\cdot}5 \text{ lb}$$

and

$$\mu_0 = 0{\cdot}155$$

In similar fashion a friction coefficient between pin and insert can be determined from Fig. 4 by taking differences in the loading and unloading curves, e.g. $(P_3 - P_4)$ lb, for a particular axial strain in the pin when a side load of Q lb is acting.

Now

$$\mu_0 = \frac{P_3 - P_4}{2Q}.$$

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DISCUSSION ON PAPERS

Discussion at Meetings · Written Contributions

Autumn General Meeting, 1956

THE AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Wednesday and Thursday, 21st and 22nd November, 1956, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, Dr. H. H. Burton, was in the Chair. During the latter part of the meeting, in the unavoidable absence of the President, the Chair was taken by Mr. J. Mitchell (*Vice-President*) and by Mr. K. Headlam-Morley (*Secretary*).

JOINT DISCUSSION ON ROLLING-MILL PRODUCTIVITY

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

"Recording Techniques for Rolling Mill Operation Studies," by *E. A. Chard, W. W. Hastings,* and *D. F. Nettell* (1956, vol. 183, August, pp. 368–375).

"The Time Characteristics of the Slabbing Mill," by *H. G. Jones, D. T. Steer,* and *P. D. Dickerson* (1956, vol. 183, August, pp. 375–386).

"Notes on the Principles Governing the Design of Ingots for High Output in the Slabbing Mill," by *H. G. Jones, P. D. Dickerson* and *D. T. Steer* (1956, vol. 183, August, pp. 386–389).

"Maximum Utilization and Problems of Wide-strip Rolling and Sheet Finishing Equipment," by *H. H. Ascough* (1956, vol. 184, September, pp. 24–46).

Mr. **D. F. Nettell** presented the paper by himself and his co-authors.

Mr. **H. G. Jones,** Mr. **P. D. Dickerson** and Mr. **D. T. Steer** presented their papers.

Mr. **H. H. Ascough** presented his paper.

Mr. **N. C. Lake** (Head Wrightson Machine Co., Ltd.): The papers which we have heard from the authors this morning have all been of great interest and full of vital and factual information.

Mr. Ascough's paper was a very timely reminder that after the plant has been installed there still remains the very considerable management problem of controlling the flow of materials.

It seems that an increase in the rolling speed will not necessarily give an increase in output commensurate with the added power consumption and the additional wear and tear upon the equipment, but an appreciable increase in output might be obtained by increasing the time that the material is actually rolling and by reducing the times of (*a*) manipulation, (*b*) reversal of rolling tables, and (*c*) the setting of the screwdowns.

The screwdown of a billet mill has recently been controlled automatically with the various positions predetermined; has consideration been given to the application of automatic position control on the slabbing mill at the Steel Company of Wales?

Mr. Ascough has referred to the possible use on the hot mill of load meters coupled to the screwdown as a means of controlling gauge and reducing differences in thickness from end to end of a strip. Has provision been made in these arrangements to take account of possible temperature variations during the rolling of strip, as these would give differences in rolling loads, producing variations in the amount of 'spring' in the housings? This would seem to need over-compensation if strip is to be produced of the right gauge throughout its length.

Many years ago troubles were experienced when producing coils of thick brass and copper strip on an underground coiler of the type now used in the steel industry. These were due to the shrinkage of the outer laps upon the inner ones, causing a relative movement between laps and a pick-up on the surface. It would appear that when coiling steel of more normal gauges troubles of this kind do not arise.

Is it considered that, in coiling heavy gauges, as now contemplated, there will be greater residual heat in the material and a greater tendency for the coil to shrink, with the possibility of heavier loads being imposed upon the mandrel?

Can Mr. Ascough give any information upon the use of wheelabrators or shot-blasting as a successful substitute for acid pickling, or is this merely regarded as a supplement to acid pickling?

There have been many discussions recently on the merits of high- and low-speed coil cut-up lines and Mr. Ascough's remarks on this subject were very timely. It was interesting to note his advocacy of a balanced plant, using both high- and low-speed lines.

It is understood that in this country a considerable volume of orders are for 1- or 2-ton lots of sheets. If these are to be produced on a high-speed line with a single prime piler the line might be running at speed for about 20 seconds and stopped for another 10–20 seconds while the separating pallets are inserted between the packs. Even with such small orders a high-speed line having a double prime piler can be operated at high speed for most of the time. It is estimated that a coil of 50,000 lb weight could be cut up into sheets, in packs of 2 tons weight, on a high-speed line running at a maximum speed of 800 ft/min, in about 10 min on a line with a single prime piler and 5 min on a line with two prime pilers.

Since the moving parts on a line with a single piler have to be accelerated and decelerated, say, 12 times per coil, with the consequent wear and tear, it would seem that there is a definite case for the provision of two pilers on high-speed lines, or, alternatively, for putting in some low-speed lines for the smaller orders.

Monsieur **Claude Biais** (U.S.I.N.O.R., Denain, France): How much time, how many people, and what kind of people do Mr. Jones and his co-authors use in making their time-studies? We have carried out some studies on a slabbing mill, using stop watches, and we found that the time analysis took quite a long time.

Mr. **W. H. Schofield** (Richard Thomas and Baldwins, Ltd.): In July and August of this year similar investigations were carried out on a 44-in. slabbing mill to determine the ultimate output which could be anticipated from the mill.

The tests carried out were less extensive than those described in the paper on time characteristics of the slabbing mill, and in fact the timing of the rolling sequence was obtained from records of the mill motor current and rev/min curves.

Curves and equations were not evolved for the time in the rolls, but several of the figures have been checked and they bear out these equations approximately, taking account of the difference in basic speeds, of 40 and 50 rev/min.

The time between passes was about double that recorded in the paper, but this is probably due mainly to difference in screwdown speeds, the method of control of the screwdown motors, and the number of operators.

The times out of rolls for both downtilt and uptilt were about 30% greater than in the paper, probably for the same reason.

The time between ingots was slightly less than in the paper, but our test was carried out over a limited period and the results were rather scattered.

The method of establishing the time characteristics was basically the same, differing only in the method of recording the data and in the actual characteristics evolved.

A conclusion to be drawn from the results of both tests is that increase in screwdown speed and improved control decreases time between passes which are non-tilting, but when tilting takes place the time between passes is governed mainly by manipulation time. This latter point is borne out by both tests showing longer times for uptilt than for downtilt operations. Was any comparison made between screwdown and manipulation times during tilting operations?

It is stated that a universal mill decreases the time per ingot by 11% because two passes per ingot and tilting are eliminated. Surely at least the second and third sets of edging passes would be eliminated completely by being carried out at the same time as the flat passes? For the range of ingots under consideration, averaging 9·5 tons, the forecast was that a universal mill would increase output by approximately 50%.

After trying very heavy drafting up to 3 in., it was decided that the heaviest draft which could readily be taken was 2 in. on flat passes on the barrel, any increase in this figure causing entering difficulties which countered the improvement from reduction in number of passes. This conclusion is in agreement with that given in the paper. We found that this draft could be exceeded when edging in the grooves, the side friction assisting in entering the slab.

When referring in the text to the effect of increase in speed, the question is whether sufficient horsepower is available. Was this ever a limitation, and what horsepower requirement would correspond to a 2-in. draft on a 60-in. wide slab when reducing from 8 to 6 in.?

One of the conclusions drawn from our test was that improvement in screwdown control was the main factor which could improve existing mill output, possibly with the adoption of automatic screwdown scheduling. The latter was felt to be a distinct possibility in view of the fact that standard reductions could be taken for all ingots, although the number and position of the sets of passes would change. What are the authors' views on the method of screwdown control?

Mr. **W. Veldhuis** (Royal Netherlands Blast Furnaces and Steelworks, Ltd.): Referring to the paper presented by Mr. Jones, two initial questions arise in regard to the time during which readings were taken.

Did the crews differ significantly in the way of handling the ingots, and if so, has this been taken into account?

Has roll diameter been taken into consideration when working out the capacity, especially so because, during the relatively short period of reading, the roll diameter might have been roughly 4% off the average?

Also, do the authors consider that anything could be gained from improved acceleration characteristics, because top speed (which is hardly ever attained) rather than acceleration sets the pace?

Again, has the procedure followed by the authors been accepted by the Company and has their report been one of the considerations affecting the relevant expansion?

The authors prove that ingot size affects output; where does quality come in, and if it does, how?

Dr. **L. N. Bramley** (B.I.S.R.A.): It is disappointing to find that the first paper, which I regard as important, has not excited very many remarks in the discussion, because to improve production and make more steel in this country, our techniques in analysing the various operations which are going on in the mill must be improved.

In a steel melting shop, one can see rows and rows of beautiful recorders and instruments. The whole place is very well instrumented indeed. Hundreds of thousands of pounds have been spent on instrumenting steel plants adequately. But go into your research departments or development departments and ask to see the oscillography equipment and you are due for a disappointment, because very few works have any adequate equipment at all.

In the first paper some of the work of B.I.S.R.A. is described, and the paper was written primarily to interest engineers in the technique of measurement of those important variables and events which will lead to increased production. B.I.S.R.A. has tried to produce, and if not produce, to introduce, the correct instruments for doing this very important work.

The paper describes the tape perforator, a digital instrument recording set quantities, and the 12-channel recorder, an analogue instrument which will record continuously varying quantities. There are not enough of them. Plenty of ordinary recording equipment is used for the routine production jobs, but there must be many times when it is necessary to get data on an experimental

basis, and the industry is very badly instrumented for this purpose.

Take one or two comparisons. In the paper a 12-channel oscillograph is described, an extremely versatile instrument. B.I.S.R.A. obtained one about two years ago and ever since it has been in almost constant use. It can measure motion, pressure, velocity—anything you like. It is a standard instrument and easily used. In the plant it can be put to work on all 12 channels in a very short time. And yet the industry as a whole in this country, with a turnover of £800–£1000 million, has only one of these instruments. The Royal Aircraft Establishment now has, or has on order, eighty of these same instruments. I cannot believe that the need of the steel industry is really expressed in that proportion.

The details given in this paper do not in any way suggest that production instrumentation is lacking; indeed, it is very good, but experimental instrumentation definitely needs improvement.

Since this paper was written, two developments have taken place. In the paper, the tape perforator, a very versatile instrument developed by B.I.S.R.A., is described as printing up to ten characters a second; now, as a result of our work, the Creed Company have developed a new instrument giving 25–30 perforations a second, and that means that digital techniques in the steel industry can be matched very much more to its needs.

Another instrument is the new 6-pen recorder which has been developed. The 12-channel recorder just mentioned has the disadvantage that the exposures must be made on photographic film, and that means the record must be developed either on site or later in the darkroom. It is much better to be able to see what is being recorded at the time. A new instrument is now available in this country with six separate pens. It has a response of up to 65 c/s, which is sufficient for the majority of experimental technology needed in the steel plants. It is easy to use and it has the advantage that the record is a visible one.

It has been asked whether anything is being done in regard to magnetic tape. The ordinary tape recorder is not in general a recorder of variables but an event recorder. It has five channels and can record five events simultaneously. Alternatively, one variable can be recorded against a time base, but it is not an instrument in which to record in digital form six or twelve variables. Ferranti's are at present experimenting with a multi-channel magnetic tape recorder, and I think it will not be very long before a device which will record simultaneously six or twelve different variables in digital form becomes available.

Another important development taking place within B.I.S.R.A. now on this question of experimental instrumentation is the development of an analogue–digital converter, and other equipment which will take in an analogue signal and give out a digital signal. This project is regarded as of great importance to the steel industry, and a lot of thought is being devoted to it. Last year, in the Steel Company of Wales, a rough form of analogue–digital converter was produced which took in a signal from a Taylor and Hobson gauge and produced a perforated tape record: but that is only a beginning. With better analogue–digital converters it will be possible to record on perforated tape all the data now recorded on charts in the steelworks, and thus a far higher factor of analysis will be possible.

There has been some attention paid to remote position control of screwdown drives. A screwdown remote position control drive which was installed by Colvilles recently to a suggested B.I.S.R.A. scheme has now been in operation for approximately three weeks, and it is well liked by the operators, who do not want to go back to the old methods. Colvilles themselves feel that they must very seriously consider putting remote position control of screwdown in all the mills under their control.

Finally, there has been some talk on the question of improving production. As some of you will know, I believe that the roughing mill can be made fully, or nearly fully, automatic, and recent developments within B.I.S.R.A. lead us to believe that we are getting in sight of it. A very flexible control will be required and we think we can take care of this also. We cannot afford to relax our efforts in this direction as there is already a fully automatic roughing mill in the U.S.A. which was installed by the Westinghouse Company.

Mr. **W. N. Jenkins** (B.I.S.R.A.): The remarks about the programming of screws and manipulators did tend to suggest the translator. This has been developed by B.I.S.R.A. and is particularly applicable to the control of screws, manipulators, feed tables and tilt fingers, etc.

With this form of control the operator can set switches according to input data. In the case of the slabbing mill, it would be the initial size of the ingot, finishing size, number of passes, etc. The appropriate settings for the mill would be given by the translator according to predetermined programmes. The optimum screwdown settings as found in the study described this morning could be incorporated in the translator and would always be available. One hundred and fifty schedules can be incorporated in a modest-size equipment.

AUTHORS' REPLIES

Mr. **D. F. Nettell,** in reply, said: Monsieur Biais, referring specifically to Mr. Jones's contribution, asked what type of men were used to carry out the analysis. Setting up punch-tape equipment is a job for an engineer, possibly a junior engineer, and it is not very difficult if the man is enthusiastic.

One point that comes out is that it may take some time to prepare this test in advance. It also requires a lot of operators if stop-watches are used. It is generally more convenient to have one man working for a fairly long time, in advance, rather than to use a number of men at one time on the job. It is also very convenient to get the whole thing well prepared in advance, with everything installed and hooked up, so that once the test starts it can be left to go its own way.

Dr. Bramley spoke of going into a steelworks and seeing rows and rows of instruments. But the question is, who reads the charts and what happens to them?

The process industry is possibly a little in advance in this field. They have developed a technique with an instrument having possibly three indicator lamps: an amber in the middle which says that the process being controlled is correct, a red which says that it is too high, and a green which says that it is too low. This type of technique was mentioned by Dr. Bramley for recording gauge on punch-tape. It was carried out in the very plant which Mr. Ascough described. The nominal gauge of the strip was set on a flying micrometer and the deviation from that gauge was recorded in tape. This gave a very quick means of analysis afterwards.

Mr. **H. G. Jones,** in reply, said: Monsieur Biais asked how many and what sort of people did the analysis of the results. We had thousands of yards of teleprinter tape and we had no analyser of the B.I.S.R.A. type, so we took instead four vacation students from the universities who were quite glad to do this work. They were each given a wooden ruler and told that each hole corresponded to 1/10 s.

The period from the end of the results till the time a report was agreed, which takes some time in addition to the analysis of the results, was three months, which was

not unreasonable considering the amount of data to be analysed.

Mr. Schofield asked two questions, the first relating to the screwdown. During our tests it is true to say that the mill was not waiting for the screwdown, so screwdown was not the determining factor. Secondly, he queried the figure of 11% for the decrease in rolling time expected from a universal mill. This applies to a particular ingot only, and is not a general figure. Our calculations followed U.S. practice, which was that the vertical rolls should be used for holding the width only and not for any edge work more than about ½ in. at any stage. Also, the figure will obviously depend on the distance between centres of the vertical and horizontal rolls. This figure of 11% decrease is the result obtained for the best known conditions likely to occur in our works. If somebody can get 50% out of a universal mill, he is doing very well and has a strong case for conversion.

Mr. Veldhuis talked about the crews. With the aid of some B.I.S.R.A. cinematograph films, it could be seen that whereas one man would lift an ingot so far and then go further in a distinct second movement, another man would lift an ingot in a single sweep. However, no differences were apparent in the rolling times, in spite of the marked differences in technique. The roll diameter was 44 in. when the tests were carried out. It has been found that the spread in observations due to other factors is about the same as the spread introduced by variations in roll diameter.

Mr. Veldhuis asked whether the estimate of capacity was accepted by the Company. It is thought to be true that the figures for peak conditions when everything was going well are adequately represented by the paper.

Dr. Bramley said that the perforations in the paper tape have been increased in speed from ten up to 25–30 per second. Our tendency has always been to go the other way, slower, in our perforation speed. The perforated tape is an extremely useful piece of equipment, and in my view will revolutionize conventional ideas on time study, but our desire is for the tape to go slower.

Mr. **H. H. Ascough:** On a slabbing mill operating at a very high tonnage rate the rhythm which an operator achieves, i.e. in matching the screwdown speed to the reversing and acceleration times of the mill, combined with the heat of the ingot, is the over-riding factor in rolling high outputs. If a slabbing mill can be presented with ingots of varying sizes at the exact temperature required, then automatic position control will be a success, but I doubt whether it is practicable to achieve such perfect conditions, particularly with large ingots. It is frequently advantageous to clear some soaking pits fast and risk temperatures below optimum so as to fill the pits with incoming hot steel.

The question of slabbing-mill acceleration has been referred to. It is important that acceleration and reversing times match screwdown speed, otherwise the advantage is lost.

With regard to automatic gauge control on hot- and cold-strip mills, it is axiomatic that the need for such control on a cold reduction mill is largely due to gauge variation from the hot-strip mill, which results from temperature gradient throughout the bar.

A cold mill running at constant speed with constant tension will normally produce uniform gauge, assuming the gauge is uniform entering the mill. Therefore, as Mr. Lake suggests, it is in the hot-strip mill that the prolem arises and where if possible the gauge should be automatically corrected. As a matter of interest we have experimented by running up No. 4 rougher, tapering the bar thicker towards the end to compensate for heat loss. This proved successful but, of course, provides speed operators with a problem. Finally, finishing speed in the hot-strip mill is significant, and by operating our mill at 2000 ft/min we can, on an 8-in. slab 18 ft long reduced to 0·083 in. thick, maintain a rundown of not more than 0·005 in.

We have experienced no trouble coiling ⅜-in. plate except that entering this material at any speed tends to push the wrappers off the mandrel, resulting in cobbles. We have also had some trouble in adjusting the gaps on the pinch rolls and wrapper rolls, but a mechanical method of adjustment is being provided.

Wheelabrators are regarded in the U.S.A. as an undesirable substitute for the orthodox continuous pickling lines.

Double pilers for cut-up lines referred to by Mr. Lake are of great interest. On our new line operating up to 800 ft/min it was felt, as experience both in the U.S.A. and this country previously indicated, that piling problems were the limiting factor on the speed of the line and we should not at this stage install two sets of trouble before one was corrected.

Mr. Schofield's comments on the figure of 50% additional output from a universal mill compared with a high-lift mill must be qualified by stating what the comparison is. If a modern universal mill is to be compared with a modern high-lift mill the figure is on average about 15%. This figure, which I obtained from the U.S.A. 4 to 5 years ago, has been confirmed by the work of Mr. Jones. The figure of 11% which he has given relates entirely to a particular set of conditions. The example Mr. Jones showed was not really good-quality rolling, as a pass in the 9½-in. hole was omitted to increase the output of the slabbing mill. Unfortunately such rolling practice does not ensure a parallel bar, leading to width variation at the hot-strip mill and subsequently to loss of yield.

Mr. Jones presents the facts, it is for us to interpret them. For example he investigated the effect of slab-scarfing on quality of finished sheet. The report implied that quality deteriorated with scarfing. Such facts were not necessarily unexpected, as presumably the very worst quality slabs were scarfed and probably all defects were not removed.

The horsepower available for the drafts indicated was 26,000. It is the torque, however, which is significant. The reason the mill speed is held down to 40 rev/min is not only to avoid damage to equipment but also to obtain quicker reversing time to match the screwdown speed. The relationship of these various motions was investigated by B.I.S.R.A. and published in a first-class report.

The distance of the vertical rolls from the horizontal rolls in a universal mill affects output, and we would have preferred this dimension to be 7 ft 6 in. instead of 9 ft, which we have been forced to accept to have roller bearings for the roll necks.

Mr. Veldhuis mentioned quality and this is one of the reasons why we are replacing our existing mill with a universal type. As stated, a high-lift mill under high output conditions does not provide time to give a uniform section, and also necessitates over-edging.

I am not quite sure that I understood Dr. Bramley's query concerning the 2 in. correctly, but we have asked him to include in our automatic control of the slabbing mill a memory device which will enable the return from an edging pass to a flat pass corresponding to the correct thickness; as it is at present, sometimes 2 in. is lost.

With regard to automatic roughing and pre-set, we have asked Dr. Bramley to consider a device for automatically setting the four roughing mills of our hot-strip mill, using, if necessary, a punched card. The number of movements are prodigious, including vertical rolls, horizontal rolls, side guards, table rollers etc. I am certain that from such a device there will be considerable benefits to us.

JOINT DISCUSSION ON BLAST-FURNACES

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

Automatic Stock Level Control on Blast-Furnaces *by I. Kjellman and K. Grönblad* (1956, vol. 182, Feb., pp. 168–170.)

The Measurement of Gas Transit Times in a Blast-furnace *by T. W. Johnson* (1956, vol. 184, Sept., pp. 18–22.)

Studies of Blast-furnace Assessment *by J. M. Ridgion and A. M. Whitehouse* (1956, vol. 184, Nov., pp. 249–257.)

Mr. **J. M. Ridgion** (B.I.S.R.A.), in the absence of the authors, presented the first paper, Mr. **T. W. Johnson** (B.I.S.R.A.) the second, and Mr. **A. M. Whitehouse** (Steel Company of Wales Ltd.) and Mr. **J. M. Ridgion** the third.

Mr. **Ridgion,** introducing the paper on blast-furnace assessment, stressed the interaction between the blast-furnace and its manager. In a general sense most of the performance figures, coke rate and blowing rate for example, were statements of what the manager had decided. His decisions on these matters must however be influenced by the response of the furnace in terms of off-grade iron, flue-dust make, stockline movement, and by the figures of the cost sheet.

The furnace and manager in fact constituted a closed-loop servomechanism in which the control mechanism was the most complex system known, and one notoriously unpredictable. Economic forces would no doubt keep the controller performance within reasonable limits of consistency but it was still possible to tell one blast-furnace manager from another.

The object of the present study was the furnace, but any examination of interrelationships between performance figures and external influences must really relate to the combined system. Some of the spread and uncertainty in the results might arise from the manager. On the other hand he might be mainly responsible for some of the consistency. In one particular case the slag volume and basicity were both independent of the ore analysis because the manager added both limestone and silica to keep it so.

Blast-furnace managers generally knew their job and reacted to changes in furnace conditions in a consistent manner. Consequently mathematical relationships deduced from operating data reflected the inherent characteristics of the furnace and should apply to other plants.

The more consistent and significant relationships quoted in the beginning of the paper should therefore have fairly wide application, and it was hoped that operators would apply them in comparing furnace performances under varying conditions and see how well they fitted.

It is perhaps of interest to note that Continental workers tend to take one factor at a time, plotting against coke rate to derive a factor which is then used to correct the fuel rates before continuing with an examination of the next factor. We feel that such a procedure begs the question as to which variables are most important. It would seem better to study all the factors at once, even at the cost of some heavy arithmetic.

Mr. **T. H. Hodson** (Kettering Iron and Steel Co.): The work of Mr. Ridgion and Mr. Whitehouse was originated in the hope of developing a method which would enable the performance of furnaces to be compared, although they might be smelting different types of ore and producing different types of iron. Unfortunately, the net result of the authors' efforts is represented by the six coefficients, for total burden, lime/silica ratio, blast temperature, percentage of hard ore, percentage of sinter, and for iron/silicon, which are put forward in their paper. These appear to be a poor harvest after the prodigious labour involved, particularly as no progress appears to have been made towards the relative assessment of different furnaces.

The fact that a basis for furnace assessment has not been established up to the present is surely an indication that the problem is an unusually difficult one. It is better, therefore, to regard the work done so far as preliminary exploration of the problems of assessment.

Examination shows that the coefficient for total burden varies from 0·084 for Redcar No. 4 to 0·277 for Bessemer No. 5. The proposed coefficient is 0·15; hence it needs reducing by 44% to suit Redcar No. 4 and increasing by 85% for Bessemer No. 5. Similarly, the coefficient of 0·4 cwt reduction of carbon for 100° C increase of blast temperature needs reducing by 67% for Sheepbridge and increasing by 25% for Bessemer No. 5. Other variables show similar inconsistency. Obviously the coefficients can be regarded as being only of a general nature and care should be taken in applying them to a particular plant or practice.

The meagre results achieved pose an important question: is it possible to assess the performance of a blast-furnace?

It may be helpful to review the basis of the authors' investigations. The first and limiting factor was that no special tests were made to provide data for the study. The only figures available were normal works' records, which were compiled for routine control and costing purposes and not for scientific investigations. Furthermore, when the job was originated the only basis for assessment was coke per ton of pig iron, because data for other bases did not exist. The carbon content of coke may vary from, say, 78% to 92%, and the silicon content of iron from 0·3% to 5·0%. Hence the yardstick was really coke of widely varying quality per ton of iron of varying quality. This is hardly a scientific unit.

Blast-furnaces are operated to make pig iron, and coke rate is a figure of vital importance both technically and commercially. Nevertheless the actual job which a blast-furnace performs is to smelt burden, which consists of iron, slag-forming constituents, and volatiles. Thus the coke rate can, in a general way, be considered as consisting of three items: (*a*) coke for iron, (*b*) coke for slag, and (*c*) coke for volatiles. The reduction in coke rate resulting from low slag volumes and from reduction of volatiles by calcining or sintering is well established. The authors had no records of slag weight or weight of volatiles to bring into their analyses.

In practice, for given burden materials the coke rate is affected substantially by such factors as the degree and type of burden preparation, efficiency of gas/solid contact, amount of solution loss, and steadiness of driving. None of these can be expressed in concise mathematical terms, and so these vital factors could not be included in the analysis.

The authors' work consisted of statistical analysis of the available data, but the data were totally inadequate. The authors did not have a chance to achieve their goal of relative furnace assessment, and so the question remains unanswered. Nevertheless, we are faced with the position that the blast-furnaces of the U.K. consume over 12 million tons of scarce and expensive coke per year, and we do not know how efficiently it is being consumed. The difficulties revealed by the present paper should therefore be accepted as a spur and a stimulant for a fresh attack on the problem.

There are so many interrelated factors which affect the performance of a blast-furnace that I cannot foresee the complete picture ever being available for a commercial blast-furnace. The chances of it being available for a number of furnaces are even more remote. It seems that an entirely new approach to blast-furnace assessment is called for.

In this connection we might find inspiration from the work of the steam engineers. In 1778 they defined the performance of their Cornish pumping engines in terms of the weight of water raised one foot high per bushel of Swansea or Durham coal. The evaluation of the mechanical and electrical equivalents of heat enabled them to adopt a world-wide standard method of assessing performance, namely thermal efficiency per cent. This unit appears to be equally applicable to blast-furnaces.

The energy which makes a blast-furnace operate is heat, heat from combustion of coke and heat from hot blast. Both of these can be evaluated. This heat ultimately re-appears in four main forms: (*a*) metallurgical work; (*b*) heat in liquid products; (*c*) losses in cooling and radiation; (*d*) total heat of waste gas. The metallurgical load depends on the raw materials charged. The heat in the liquid products depends on the slag and iron temperatures, which must be appropriate to the metal analysis required. The cooling losses are necessary and reasonably constant, and also relatively unimportant. Hence for all practical purposes the inefficiency of a blast-furnace lies in the total heat of the waste gas. This includes the calorific value and sensible heat of the gas, plus the latent and sensible heat of its moisture content.

The ratio between total heat of gas and the heat input (coke + blast) would provide a useful index of furnace efficiency which could be used as a basis for blast-furnace assessment. It would not be difficult to establish a standard technique for evaluating thermal efficiency on these lines. Once this has been done the next step would be to take the appropriate records of one furnace continuously and make any convenient changes in coke quality, proportion of sinter, blast temperature, burden preparation, and so on. This would yield a mass of figures needing analysis by the statistical methods developed by the authors. Similar tests could be run on other furnaces and the relative performances compared.

The authors mention that the absence of adequate data prevented them from obtaining satisfactory explanations for variations in driving rate. It is generally accepted that the capacity of a furnace to burn carbon is a function of hearth diameter. Carbon rate with a given burden depends on furnace efficiency. It appears probable, therefore, that statistical analysis based on furnace efficiency would yield highly significant figures for iron production, which, as the authors state, is the ratio between carbon consumed and carbon rate.

Major **W. R. Brown** (Ashmore, Benson, Pease and Co.): The paper on stock-level control is welcome because it tells how an instrument in common use in this country is put to a somewhat different purpose in Finland. But it is rather surprising that they have chosen the intermittent type of instrument, whereas the continuous type is almost invariably used elsewhere. The latter is certainly the more informative as it clearly shows the manner in which the stock descends within the furnace. The reason given in the paper, that the intermittent type is better suited to the temperature conditions in a foundry-iron furnace, is not borne out by experience in this country. A famous foundry-iron furnace, barely twelve miles from here, has successfully used a continuous stockline recorder for more than twenty years.

To claim that this instrument can control the stock-level is to rather overstate the possibilities. The instrument can be made to dump the large bell automatically but there would be no object in doing this if there were not a charge on the bell ready for dumping. If the charge is on the bell, the scale-car operator is available to initiate the movements which open the bell. It is here that the procedure in Finland differs from ours; they are content that the bell is opened automatically but British operators prefer to retain control so that the bell will not be opened during a heavy furnace slip or at other inconvenient times.

One feature described in the paper is certainly to be commended. When the bell movements are controlled by hand, there remains the possibility that the bell may inadvertently be opened when the furnace is already full, with no room for further incoming material. The interlock which prevents the bell opening when the stock-measuring device shows the furnace to be full is therefore a useful safeguard.

In papers such as the one on gas transit times, it would be helpful to the practical furnaceman if authors would explain the object of their work. Is it intended as a contribution to fundamental research, or does the author foresee the use of his technique as a routine method of acquiring information, the tests being made daily or hourly by the furnace staff?

In the paper on furnace assessment, certain coefficients have been evolved for some variables over which the operator has no control. It would be very much to the point if this process of assessment could establish exactly what value can be attached to varying degrees of high top-pressure, say 5, 10, and 15 lb/in^2. It would also be most helpful to know, with more certainty than we do at present, the benefit gained by screening coke, and to discover at what point optimum results are obtained—should we reject $\frac{1}{2}$, 1, or $1\frac{1}{2}$ in.? Armed with reliable knowledge on these points, the furnaceman can arrange his operation accordingly.

Mr. **A. Stirling** (Stewarts and Lloyds Limited): Messrs. Ridgion and Whitehouse are among the very few people in this country who could attempt such a detailed study of blast-furnace assessment as is given in their excellent paper.

Table I would be improved if the size of the furnace mentioned, together with hearth diameters and the useful working volumes, were included; the age of the furnace in its campaign might also have been added, together with the coke-burning capacity on some unit basis, such as the Rice rating. It would have been appropriate to have shown the Fe balances; one wonders if the authors would expect an Fe balance to within 3% and if they would agree this as a reasonable basis from which to begin their more complex studies.

If the weight of the burden and the coke are closely interrelated, is not the sum of these two, the weight of the total materials required to produce the iron, an important variable? In the prediction of coke rates, which involves a knowledge of slag volumes, is not the weight of the burden minus the slag volume, what might be called the gangue-free burden, an important variable?

The Bessemer No. 5 furnace stands out in the paper on a much higher level than the others, which might

almost be regarded as one in the extent to which their performance has been explained.

Mr. Ridgion has dealt rightly with the concept of stating the variables in descending order of importance. The point is, of course, that no order, either descending or ascending, is known, and we cannot be sure that the variables themselves are all known. Moreover, there is the problem of confirming that conventional variables are the most appropriate: for example, while much information is available about the silica/lime ratios of ores, many operators would agree that for some practices the alumina/silica ratio would be the more telling criterion. It is to be hoped that this paper will also be discussed elsewhere and perhaps at a joint meeting with the Industrial Applications Section of the Royal Statistical Society, so that it may become better known.

While the coefficients which have been given are of interest, there is, presumably, no intention of producing a national formula. The range of iron-making practice, to say nothing of the contrast between the newest and the oldest plant in this country, is so wide that an overall statement could only have a very limited value. The methods which the authors have used are of course within the reach of few investigators, much less plant operators, and if, having explored the problem so well by these refined techniques, the authors could now indicate how operators might improve their record-keeping and statistical information generally so as to assist studies of this kind, we should be further indebted to them.

Mr. **H. G. Jones** (Steel Company of Wales Ltd.): I want to underline some of the difficulties of this work of blast-furnace assessment, which are, of course, well known to the authors of the paper on this subject. It is no use simply putting all the observed figures into a regression analysis and hoping that the arithmetic will sort them out. The first and most obvious point is that the factors classified as ' causes ' must be primary causes and not secondary causes of the variation being examined. In some of this blast-furnace assessment work we may be treating the secondary causes and not getting down to the fundamentals of the problem.

On rather a technical point, trend removal is essential but can give the wrong results. If the effects are curvilinear, as most of them are, then, if the observed figures are heavily weighted around one end of the distribution, this method of trend removal can be shown to give the wrong values for the coefficients. It is dangerous to apply trend removal until information is available on how the variation takes place.

As a positive suggestion for future work, I believe the next move is to consider one blast-furnace in detail and to check the data on that week by week as it arises. If a change is made, the reason for it must be found. The method of statistical analysis can then be applied to the results obtained after such a trial. This might enable the chemistry of the plant also to be considered so as to put the investigation on a physical as well as a statistical basis.

Dr. **S. Klemantaski** (B.I.S.R.A.): Perhaps the authors of the paper on blast-furnace assessment would like to comment on the absence of top-gas temperature from their variables. The importance of the variability of, and the frequency of variations in, the quality of the materials supplied to the furnace should not be ignored. For example, in a burden with two components, the average for the week being 50% of each, it must be very important, from the point of view of the efficiency of furnace operation, whether the composition remained constant at 50% during the week or fluctuated repeatedly and widely. In the latter case it would obviously be much more difficult for the operator to maintain his efficiency as high as it would be if the burden and charge remained more or less constant. The same effect is possible through variation of properties within a given ore, particularly in home ores, which might vary widely within a week. An investigation of such effects might well reduce the unexplained deviations.

The absence of any indication of the charging cycle or of any index of distribution of material in the furnace is rather surprising. In the U.S.S.R., where it is apparently hoped to operate blast-furnaces with automatic control at high efficiency, distribution is an important parameter, so that one would expect it to be important for assessment also.

Dr. **J. H. Chesters** (United Steel Companies Ltd.): Many of the results quoted by Mr. Ridgion and his colleagues would appear to be in line with our experience in the United Steel Cos. Ltd.—in particular we have observed the marked decrease in coke rate with increasing use of sinter. It would be helpful in this connection if the authors could state the range covered in determining their coefficient, since this would clearly be more significant if based on the range 0–100% rather than on, say, the range 0–20% or 20–40% sinter. We would also like to know whether the relationship was linear within this range. Would the authors not agree that the actual coefficient would vary with the type of material which the sinter replaces? If, for example, high-grade ore were merely crushed and resintered, one would not expect any appreciable change in coke rate, but if the ore showed a big loss on ignition then a substantial benefit might be expected. Even with a given chemical composition one might also expect differences in coke rate with varying physical properties, e.g. the shatter index.

Dr. **D. W. Gillings** (I.C.I., Ltd.): Mr. Hodson made an interesting point in suggesting that a comparison might be made between the determination of the efficiency of the blast-furnace, and of steam raising and power generation. The efficiency of these well-established processes can be stated clearly on a thermodynamic basis, but the oversimplification which would be incurred by a direct extension to the blast-furnace process may well be unacceptable. The proportion of total heat appearing in the top gas can be influenced by changes of coke reactivity alone, which may not necessarily affect the main process of iron reduction. Such changes may simply affect the reaction between the coke and the CO/CO_2 mixture. It has been pointed out* that there are instances in which the apparent efficiency of combustion may approach 100% but the efficiency of the chemical process, for instance carburation of metal in cupola melting, may be quite different because of differences of conditions influencing oxidation and reduction reactions. A good deal of study of the efficiency of chemical processes is now being carried out in the course of chemical engineering and process research. The results of such study should be of interest and assistance in understanding blast-furnace processes.

In the statistical analysis of blast-furnace processes, the task amounts to the determination of process characteristics, or more strictly the coefficients of expressions relating process efficiencies (on various standards) to operating conditions. This must be done on the basis of information which is incomplete in several different ways. In particular, while the information on the values assumed by some variables may be completely recorded, that for other variables may only be expressed in the form of limits within which most values fall, while for others, the information may be virtually non-existent.

* G. Tarocchi: Oxidation and Reduction in the Cupola: Papers to 21st International Foundry Congress, 1954: Translation to appear in *Foundry Trade Journal*.

There is however another source of information, deriving in a way from the plant–manager relation. Although the total of explicit information may really be incomplete for the purpose, the manager still succeeds in running the plant, and this information ought to appear somewhere in the analysis in every case. Techniques for the statistical analysis of operations and experimental results have been under continual development in both experimental and mathematical fields, the latter on the basis of extending and refining programming and scheduling theories, both for use as such and in combination with correlation methods and statistically planned experiments. A few examples of this sort of investigation have been reported, mainly from the petroleum industries, and the work should be of interest to those pursuing the analysis of blast-furnace operation. The computational task is still regarded as formidable, however, and can of course only be contemplated because of electronic computer development.

Dr. **T. P. Colclough,** C.B.E.: When studying the paper by Ridgion and Whitehouse one is left in some doubt as to the method of attack and the validity of the so-called conclusions. In applying the statistical method, one takes all and sundry data that are available and seeks to find some common measure of agreement or relation between them. Is this the most suitable and useful way to tackle this problem?

In trying to establish the basis of correct blast-furnace procedure, the unsatisfactory procedure and bad practices which have been prevalent in our old and obsolete blast-furnaces should be discounted. The best practice which can be found should be examined to see what lessons can be derived. It may not be the best way to use our skilled staff by letting them spend their time in examining a variety of practices and trying to correlate them. From now onwards, having experimented with the new methods and having found a way to use the new mechanical apparatus, our efforts should be concentrated on trying to get the correct results from the best operating data that are available.

In the present method of assessment, the fundamental basis adopted is the weight of the burden charged to the furnace. This, however, is not the most important factor and cannot be in view of the varied characteristics of different types of ore. After all, the blast-furnace is a heat machine and, in my opinion, the only correct basis of assessment and computation must be the heat requirement of the burden and the utilization of the fuel that is put into the blast-furnace. In the present method of assessment heat units, as such, find no place, and to this extent the assessment cannot be regarded as satisfactory.

The best correlation in this paper is shown in blast-furnaces where the conditions of operation are known to be under stringent control as compared with others where the control is much less efficient and the same correlation is not shown. However, even when the authors reach conclusions, using these new machines and this new method of approach, the significance of the results is of the order of 50%. Apparently, tossing up a penny might give results as good as applying this extremely good but complicated research method. Progress must be made by selecting the best practice in the world and trying to find a correlation between the various factors in that practice.

The authors have been at pains to emphasize that the factors they put forward are not to be applied over a wide field but relate only to a relatively narrow field, and how right they are!

A blast-furnace is a heat engine. The changes made in the burden, blast temperature, sinter weight, basicity of slag, etc., are all variations in heat requirements. Therefore, one may ask what the relation is with regard to heat requirements and if they can be correlated. The only source of heat is in terms of carbon or coke. The authors mention the changes which take place in carbon requirement with changes in burden weight, in silicon content and in blast temperature. They say that if there is a change of 1% in the silicon content of the iron there will be a change of 1·2 cwt/ton in the carbon consumption. This is in line with current experience and on that basis the amount of heat which is generated is 2100 B.t.u./lb of additional carbon. An increase of 1 cwt in the burden will represent an increase of about 84 lb slag because the additional weight must be either volatile material or gangue, the weight of iron oxide is not changed. The heat requirement of slag is known and, in effect, an increase of 1 cwt in the burden represents an additional heat requirement of about 63,000 B.t.u. per ton of iron. The authors state that this change means an increased requirement of 0·15 cwt, or 17 lb, of coke, so that the heat generated from this extra coke is 3750 B.t.u. per lb.

Taking the third factor which is recommended as being reliable, increasing the blast temperature by 100° C saves 0·4 cwt, or 45 lb, of carbon per ton of iron. The amount of heat supplied in 100° C extra blast temperature is known and it means that in this case 1 lb of carbon is equivalent to 8000 B.t.u. The aim of this paper is to note correlations of significance, but the three factors given by the authors show this wide variation between 2100, 3750 and 8000 B.t.u. per lb of carbon employed. What is the explanation?

Mr. **R. P. Towndrow** (Colvilles Ltd.): When this work was started, admittedly in a very crude way, nearly eight years ago by our organization, we had some fairly limited objectives in mind in the first place, and the first of these was to try to give blast-furnace managers some idea of whether or not their furnace was doing what it ought to do in relation to the conditions which were imposed upon it; consequently it is not at all surprising to find that, having made the best account possible of the variations brought about by certain known circumstances, there still remain some discrepancies to be accounted for. If the blast-furnace manager was perfect in all his judgments, and if the assessment technique was perfect in all its aspects, there would be no discrepancies. Those which remain may be accounted for partly by defects in the technique of analysis and partly by faults in managerial judgment.

It was felt to be important, however, that a blast-furnace manager should not try to make his furnace do something which metallurgically and thermally it was incapable of accomplishing, because that would only lead to disaster. That, however, is what managing directors usually ask him to do, because, however well he is doing, or thinks that he is doing, they naturally want him to do better, and so does he, for that matter. If he tries to make his furnace do something that it cannot do, the usual result is disaster, so that he has to find what new conditions he needs to apply to effect an improvement. That was the first and simple objective.

Secondly, at that time there was a good deal of discussion on other subjects, which resolved itself into an argument by blast-furnace managers on the effect of this and that on their practice. In other words, at that stage an absolute standard of perfection in blast-furnace work was not wanted, but rather a way to account for the variations which appeared to exist with practices which were ostensibly identical. To a very large extent, to the extent measured by the discrepancies which still remain, the work which has been done has made a big contribution to the attainment of that objective.

This work, however, was started eight years ago, and

many of the data which have been used are data which were current a good many years ago, and must already be out of date.

What has happened since that time? At least one beautiful classical experiment has been carried out on a blast-furnace plant, namely the conversion of a plant which operated on partly screened and partly sintered burden to one working on completely sintered burden, an experiment of the type which was not envisaged when this work was started. The work of a good many of the plants incorporated in these data has been very considerably improved in recent years. It would perhaps be flattering the work of those engaged in assessment to suggest that the improvement has been to some extent stimulated by the work which they have been doing.

Either the assessment work has stimulated better results or the blast-furnace managers have made this extra effort without any stimulation. Perhaps it is a little of both.

Dr. Colclough is right in saying that to get an absolute measure of what a blast-furnace ought to be capable of one must start from fundamental thermodynamic principles, but that is not what was attempted in the first place. The aim was to give the blast-furnace manager some measure of the changes which he might expect in his practice from changes in the things he used. It was not possible to say that if all the pieces which went into the blast-furnace were of the same size certain results would follow, because we had not the data for such a calculation; but Dr. Colclough has on many occasions made such calculations for our benefit.

Dr. Colclough and those who are doing this assessment work are to some extent talking about two rather different things. One is the technique to find out the absolute peak of efficiency which a blast-furnace can theoretically attain, and the other is the work done so far to explain to what extent the changes experienced in practice are due to plain stupidity and to what extent they are the direct result of changes in operating variables outside the control of management altogether. It is essential to distinguish between them, because to change the second the directors have to sanction a new sinter plant, the buyer to buy different ores and so on, whereas to change the first it may be necessary to sack the present blast-furnace manager and get a better one. Since it is essential not to sack the blast-furnace manager because you have no sinter plant and not to buy new sinter plant because you have a stupid blast-furnace manager, it is very important to be able to distinguish between these effects.

CORRESPONDENCE

Monsieur **C. G. Thibaut** (Association Technique de la Sidérurgie Française) wrote: A general study of the performances of many blast-furnaces has produced a method* which permits the comparison of the operation results.

The coke rates of 85% C coke are adjusted to a constant blast temperature and silicon content of the iron and a standard amount of carbon burned in 24 h.

Under these conditions, it appears* that, on an average, the coke rate M is a third of the net weight Q of the burden (i.e. excluding flue-dust).

For example, a burden of 3000 kg/tonne of iron produced (ores and additions per tonne of iron) requires on an average 1000 kg of 85% C coke per tonne of iron produced with a blast at 750° C, nominally for the manufacture of 0·50% silicon iron.

If the weight of the burden Q decreases to 2400 kg/tf, the coke rate falls to 800 kg/tf.

In British units, these figures become:

Total burden less flue dust, cwt/ton pig	Coke consumption, cwt/ton pig
60	20
48	16

Taking into account this mean factor $Q/M = 3$, the coke rates become comparable for a ' standard ' weight of burden, e.g. $Q = 3000$ kg/tf (60 cwt/ton). The corresponding *unified* coke rate is 1000 kg/tf (20 cwt/ton).

Naturally, this is only a rough figure, but it is valuable in the appreciation of the working of one blast-furnace compared with that of another or compared with the working of the same furnace at a different time.

In a general way, one can state that a unified coke rate below 1000 (20 cwt) is satisfactory. If it is higher than this one must look for the reasons, which could be for example:

(i) irregular working of the furnace
(ii) faulty charging equipment
(iii) excessive density of the ores (i.e. ' hard ' ores)
(iv) the quality of the coke, etc.

The unified coke rate, although expressed in terms of weight of coke, represents in effect the quantity of heat consumed in order to produce 1 tonne of iron. This thermal character is confirmed by the close correlation between the unified coke rate and the CO/CO_2 ratio of the flue gas:

$M =$	900 (18 cwt)	$CO/CO_2 = 1{\cdot}8$
	1000 (20 ,,)	$= 2{\cdot}3$
	1100 (22 ,,)	$= 2{\cdot}8$

This method of analysis is based on observations which do not make claim to absolute mathematical precision. It is based on considerations analogous to those of Ridgion and Whitehouse. A thorough study of their conclusions show that the two methods can complete each other.

Our views hardly differ, except in the choice of the carbon rate as a dependent variable. The author, and no doubt most continental experts, consider that the rate of combustion can be regarded as an independent variable. In effect, about 85% of the coke is, on an average, burned by the blast. It is, therefore, essentially the blower—and finally the man who controls it—which determines the carbon rate, at least in the first approximation.

Studying the coke consumption statistically as a function of the coke rate, it is observed that, on an average, a variation of 10% produces a variation in the coke rate of 2–4% in the same direction.

Mr. **C. E. Sayer** (McLellan and Partners) wrote: As the authors say in the introduction to their paper, the results of their studies of the various factors affecting blast-furnace behaviour are intended to show operators what may be expected from any change of conditions on existing furnaces. As such they should be of great interest and value.

There is, however, another aspect of blast-furnace assessment to be considered, namely, the prior assessment of the operating results of a projected furnace. In making calculations of this kind two factors exert considerable influence on the results, especially on the calorific value of the blast-furnace gas. The first is the heat release (possibly best given as per ton of iron) required to maintain the necessary heat balance in the furnace, and the second is the nitrogen absorption factor, as a result of which the actual proportion of nitrogen in the blast-furnace gas is apparently always less than that derived from theoretical calculation. Any information the

* *Centre Doc. Sidér. Circ. Inform. Tech. No.* 3, 1955, pp. 563–582.

authors may have available on these points would be welcomed.

AUTHORS' REPLIES

Mr. **A. M. Whitehouse** (in reply): Mr. Hodson pointed out that the coefficients given for individual furnaces were incompatible with the overall coefficients derived after reviewing a number of equations. The tremendous variability which exists must be emphasized. The coefficient of any individual furnace standing by itself has very little reliability.

Mr. Hodson was disappointed that a comparison of different furnaces had not been made. The work has not gone nearly as far as that. The first objective is the practical one of helping furnace managers with a few facts which are thought to be of some genuine applicability.

The variables used were chosen from the operating variables of which records are kept on a routine basis in most blast-furnaces. Several speakers have raised the question of inaccuracies of recording and of the absence of certain variables. Some have gone further and criticized the use of this kind of variable at all, suggesting, for instance, an approach using variables measuring heat transfer. The inaccuracies and omissions are only to be expected in a complicated system like a blast-furnace, and do not invalidate the work, provided the variables which are recorded are not biased, and cover vital aspects of the process. As for a change in approach taking more account of blast furnace theory, this would be welcomed so long as variables can be provided which are universally accepted theoretically.

Dr. Colclough maintains that the work should have been based on good practice. To attempt this would beg the question as to what is good practice. It is better to cover a reasonable range of practice, rejecting only on the grounds of unreliable data.

I do not know whether Dr. Colclough meant seriously that a significance of 50% was the same as tossing a coin. Actually the percentages given refer to variation accounted for by each equation, and indicate the total effect of the variables included as compared with the effect of all other factors, i.e. those not included and those which may be immeasurable or unknown. The statistical significance is not the same thing. For each factor included it is clearly indicated in the paper, and only factors which have a chance of less than 1 in 20 of having occurred by accident are included at all. Most of the chances are very much more remote than this. The six variables which have been selected and shown in the list at the beginning of the paper have shown high significances independently for several furnaces. There is no reasonable doubt that they affect carbon rate, nor of the direction of the effect, although the values of the coefficients must be considered approximate.

Mr. **J. M. Ridgion** (in reply): Mr. Hodson's question about the use of a variable which is the percentage of the total heat input that appears in the top gas is interesting. It is doubtful whether this would get us very far, but it is worth trying. Is there any plant which can give regular and even slightly reliable values for top gas analysis ?

Major Brown asked for the inclusion of additional variables, and mentioned high top pressure. A study of this type, not reported in the paper, is still in progress. It relates to the performance of a furnace on normal pressure which will eventually go to high top pressure, and is designed to establish the corrections to be made subsequently to high top pressure performance. His other suggestion was coke screen size. Here the work already done may be of some slight assistance. The direct controlled experiment is the best way of tackling this. In certain experiments it is impossible to keep all the other variables constant, but the changes may be fairly small, and such changes can be compensated for without serious error by our coefficients.

Mr. Stirling asked for information to be given on the size and age of furnaces. It is a curious coincidence that the hearth diameter is 18 ft 3 in. $\pm$ 3 in. in all those studied. His suggestion of additional variables such as gangue-free burden will be borne in mind.

Mr. Jones raised a difficult question on the disentangling of cause and effect relationships. My observations on the interaction between furnace and furnace manager are an example of the difficulty of deciding between cause and effect. He also made the point about changes being made by the management during the operation of the furnace. A management in this country has promised to keep a daily diary of operations on one furnace, and when more coke is put on the reason will be noted. The idea is that after a certain number of weeks it may be possible to make a statistical analysis with rather more intelligence.

Dr. Klementaski referred to the absence of top gas temperature. The top gas analysis is not known, so that the top gas temperature would not seem to matter. On the question of distribution and the effect of change of charging cycle, with one of the Redcar analyses there was a change in the order of charging cycle about halfway through the period studied. The coefficients which had been obtained from that furnace were taken and all the coke rates for the whole period corrected, which gave a fairly level wavy line, and comparing these corrected figures with charging systems *A* and *B*, there was no difference. That, however, is only an isolated case.

Dr. Chesters' remarks on the influence of sinter are encouraging. There is a much more consistent relationship between coke consumption and the burden than between coke consumption and the slag. The work at Appleby-Frodingham, in which from a purely thermal point of view large quantities of volatiles have been removed and a reduction of 5–6 cwt in coke rate has been achieved, confirmed this.

Dr. Chesters is manifestly right when he asks about the range of sinter; 20–40% is about the total range in this study. On the question of whether the relationship is linear, the available data are not sufficient to establish whether it is linear or curved. No claim is laid to anything like such a degree of accuracy.

Dr. Colclough has asked for an explanation of the difference in apparent B.t.u./lb. of carbon implicit in the coefficients. The combustion of 1 lb of carbon preheated to 1500° C, by air at 600° C, gives a mixture of carbon monoxide and nitrogen with a sensible heat content above 0° C of about 6600 B.t.u. Processes which can only make use of heat at a high temperature can extract but a fraction of this figure from the gases; for example, only 2100 B.t.u. are available above 1300° C.

As reduction of silica mainly occurs above 1300° C, Dr. Colclough's first figure is justified. The burden figure involves a heat demand over the whole temperature range 15–1500° C with preponderating requirements around 1000° C for carbonate decomposition and above 1200° C for slag fusion. The figure of 3750 B.t.u. quoted by Dr. Colclough available above 700° C is in line with these facts. The effect of an increase in blast temperature is to increase the proportion of the total heat in the furnace available above a given temperature, and is not so amenable to direct calculation. On theoretical grounds one would expect a coefficient higher than 0·4 but this is not borne out in practice.

Mr. **T. W. Johnson** (in reply): It is odd to find such a practical thing as putting something in at the bottom and making it come out at the top being overshadowed by such an impractical thing as statistics! In reply to Major Brown, it is very difficult to say where this can lead. There are very many other things to be measured on the furnace, and B.I.S.R.A. are trying to measure some of them accurately.

JOINT DISCUSSION ON TOTAL HEAT

This discussion was based on the following papers (the dates of publication in the *Journal* are given in parentheses):

- **"The Enthalpy and Specific Heat of Iron and Steel. A Critical Survey of the Methods of Determination,"** *by J. R. Pattison* (1955, vol. 180, August, pp. 359–368.)
- **"An Analysis of the Available Data on the Total Heat of Commercial Steels,"** *by J. R. Pattison* (1956, vol. 183, May, pp. 64–68.)
- **"The Enthalpy of a 0·12% Carbon Steel,"** *by J. R. Pattison and T. H. Lonsdale* (1956, vol. 183, July, pp. 284–286.)
- **"The Enthalpy of Pure Iron,"** *by J. R. Pattison and P. W. Willows* (1956, vol. 183, August, pp. 390–403.)

Dr. **J. R. Pattison** (B.I.S.R.A.) presented the papers.

Dr. **R. W. Powell** (National Physical Laboratory): Rather more than 20 years ago when the Thermal Treatment Sub-Committee approached the National Physical Laboratory on the matter of acquiring specific heats, thermal conductivities, and expansion coefficients of steels, and suggested that a large series of steels should be investigated, considerable thought was given to each item. For specific-heat determinations the adiabatic type of high-temperature calorimetry was eventually adopted, largely because it was felt that if a 'drop' method were used, the materials would be passing through transformation regions and possibly certain amounts of the higher-temperature phase might be quenched in and retained to lower temperatures. It seemed preferable, at least in the first instance, to work with materials in as stable a state as possible. All of the samples were thoroughly annealed, and the constants were evaluated at steadily increasing temperatures. That is the vital difference between the original N.P.L. work and the quenching method which is under discussion. It also probably explains some of the differences between the N.P.L. data for steels and the Japanese data.

Recent work has shown that even with pure metals quenching can retain some of the vacancy effects which it is thought develop in the region of their melting point. Several experimental investigations have been carried out with fine wires of gold and platinum, heated electrically to temperatures close to their melting points and then quickly cooled in an atmosphere of helium. Measurements have subsequently been made, at room temperature, of their electrical resistivities and densities, and the differences between these values and the values for the initial state of the wires give information on the extent of the quenched-in vacancies and other lattice dislocations. Thus even for relatively pure metals it can be seen that quite different results will be obtained on a rapidly cooled sample and on an annealed one which is adiabatically heated.

The work that Dr. Griffiths and Mr. Awbery carried out on this series of 22 steels, and on pure iron, covered the period from 1936 until some time during the war. The measurements appeared satisfactory to temperatures of the order of 950° C, then difficulties arose, largely because the thermocouples were in actual contact with the specimens and not fully screened and earthed. Working under vacuum conditions, their apparatus began to behave rather like an electronic valve, and the thermocouple readings were affected by spurious e.m.f.'s.

Since the war Mr. Backhurst has worked on the extension of that same method to obtain results into the molten-iron region. There have been a tremendous number of experimental difficulties to overcome, and Dr. Pattison was fully justified in taking a shorter cut to obtain the values required, and he is to be congratulated on carrying out a most comprehensive and useful piece of work in a relatively short time.

At the National Physical Laboratory an alternative high-temperature method was also adopted. Dr. Pallister used a **U**-shaped specimen which could then be passed through the furnace and into the specimen in series with the furnace, their resistances being so matched that during the short period of heating both the furnace and the specimen would increase a few degrees in phase with one another. From those measurements, Dr. Pallister was able to extend the data for specific heats of pure irons and steels to about 1350° C.

It is rather unfortunate that subsequently, when the British Iron and Steel Research Association were analysing these data and preparing them for publication in the bibliography on the physical constants of irons and steels, the results of Dr. Pallister and those of Dr. Griffiths and Mr. Awbery were averaged, so that some very real differences which occur in the transformation region are not apparent. Referring to the probable specific-heat values tabulated by Dr. Pattison at the beginning of page 367 of vol. 180 of the *Journal*, for the range 100–600° C the tabulated values agree with both sets of data. At 700° C Pattison gives 0·221, Griffiths and Awbery 0·209, Pallister 0·220. At 800° C, the corresponding values are 0·204, 0·189, and 0·199, and at 900° C, 0·173, 0·190, and 0·157. The differences which now become apparent in the 700° to 900° C region are considerably greater than the anticipated experimental uncertainties.

In connection with the figure of 65·5 cal/g given for the latent heat of fusion of iron, the Thermal Treatment Sub-Committee became interested in that quantity just before the war, when Mr. Awbery made an analysis of data existing at that time, which indicated a value of 64 to 65 cal/g.

Finally, reference should be made to a paper by Dr. Griffiths and Dr. Pallister[1] on the specific heat of austenite and martensite. Specific-heat measurements were reported on a ball-race steel that had been quenched to a temperature of 150° C, where it could be retained in the austenitic state. From these measurements the specific heat for γ-iron was found to be 0·135, compared with 0·125 for α-iron. Martensite, formed by quenching

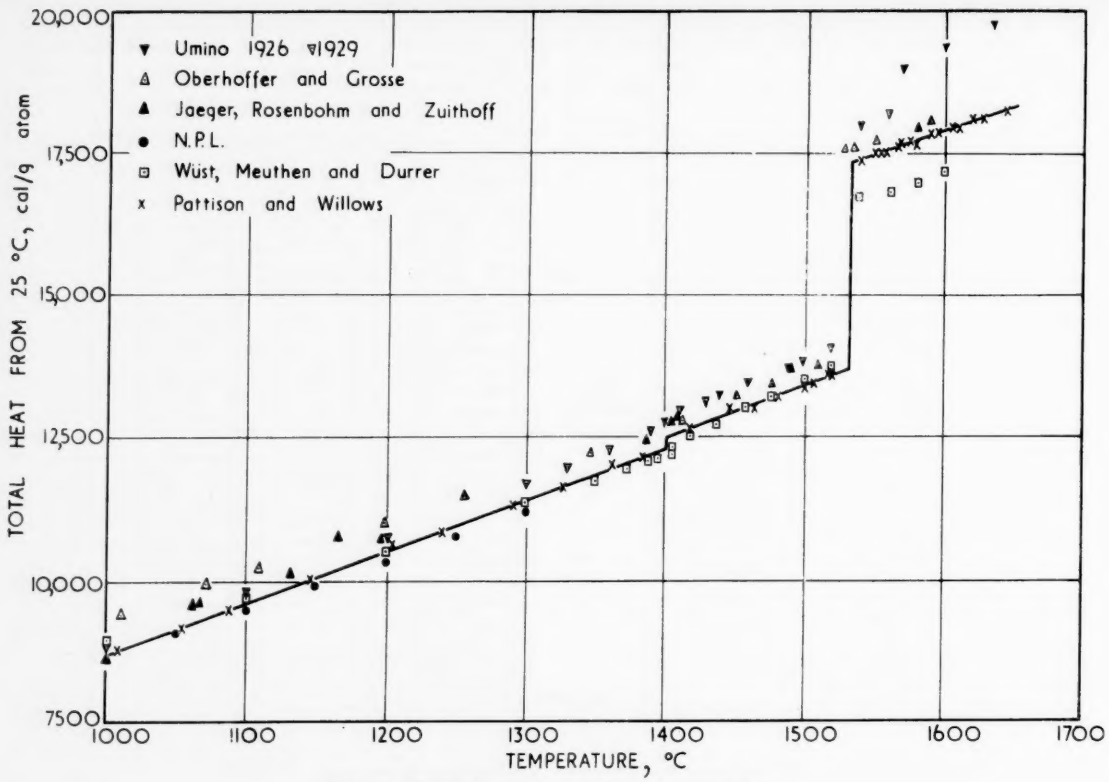


Fig. A—Enthalpy measurements on pure iron

to room temperature, was found to have, within experimental error, the same specific heat as ferrite plus carbide. These results are of interest in relation to the work now under consideration where the samples are also quenched.

Monsieur **M. Olette** (IRSID): Dr. J. R. Pattison and his co-workers have to be congratulated for their very interesting piece of work on the enthalpy of pure iron and commercial steels. I am in full agreement with the conclusion of Dr. Pattison's critical survey of the available experimental data in that field, that is to say, the necessity of further investigation. With Mr. P. W. Willows he has built a calorimeter which seems to be very simple to operate and particularly convenient for measurements on technical substances. The numerous enthalpy measurements which have been done by the authors on pure iron and on a 0·12% carbon steel seem to be among the most reliable, especially above 1400° C, but there are a few particular points to be examined.

First, why do Dr. Pattison's computed data for the total heats of pure iron differ significantly from those of K. K. Kelley[2] and L. S. Darken and R. P. Smith[3] (to which no reference is made in the bibliography) in spite of the fact that the basis for the calculation seems to be the same important papers: Oberhoffer and Grosse, Umino's last paper, Jaeger, Rosenbohm and Zuithoff? For example, the calculated figures for H_0^T in calories per g of iron at 1300° C and 1600° C are:

	1300° C	1600° C
Kelley	212·7	334·8
Darken and Smith	213·0	330·8
Pattison.. ..	210·4	326·5

It is likely that this disagreement originates from the importance given to the various literature data and it would be interesting to know what are Dr. Pattison's reasons.

There is a second question about Pattison and Willows' experimental results. Plotting on the same graph the main previous enthalpy measurements on pure iron and Pattison and Willows' experimental data (Fig. *A*), it is clear that the authors' results are systematically slightly lower than the others, except those of Wüst, Meuthen and Durrer, and from N.P.L. But, according to the authors themselves, there is some doubt on the reliability of Wüst and others' results, and N.P.L. data were not directly obtained but deduced from specific-heat measurements. Although Pattison and co-workers had discarded the idea, the formation of steam when the hot specimen is touching the water in their calorimeter would have explained this general disagreement between their results and the previous ones.

For the purpose of checking the authors' results, it would be interesting to compare data obtained with their calorimeter and data from the literature, on a substance which could be considered as a standard, for example, pure crystallized alumina. Some results on the enthalpy of alumina can be found in the authors' paper (Appendix VI, Table X) but they are higher by about 2 or 3% than previous determinations of Shomate, Ginnings, or von Gronow. Perhaps this is due to differences in composition or structure of the alumina as compared to the alumina specimens used by the previous authors. It is now possible to obtain specimens of very pure synthetic sapphire from the United States, the enthalpy of which have been carefully measured by the National Bureau

of Standards.[4] It would be interesting for Dr. Pattison to confirm his data in doing measurements on this product.

Figure *B* shows an improved adiabatic dropping calorimeter which has been built at IRSID, in which the heated specimen is received in a heavy copper block surrounded by a water bath, the temperature of which is controlled to be equal to that of the block by means of an electronic servo-device.

The calorimeter was calibrated electrically. There is in fact no serious objection to electrical calibration of a metal-block calorimeter. In our case the heater is enclosed in the block in a small space filled with helium. The calibration was confirmed by measurements on pure alumina of two different origins, French (Société d'Electrochimie et d'Electrométallurgie d'Ugine) and American (National Bureau of Standards). The results were:

		H^T_{25} in cal/mole	
		850° C	1227° C
IRSID	French pure corundum 99·9% Al_2O_3	22,352	33,934
	N.B.S. synthetic sapphire 99·98% Al_2O_3	22,349	
K. K. Kelley[2]		22,407	33,920
G. T. Furukawa and co-workers[4] (Bunsen type calorimeter)		22,343	...

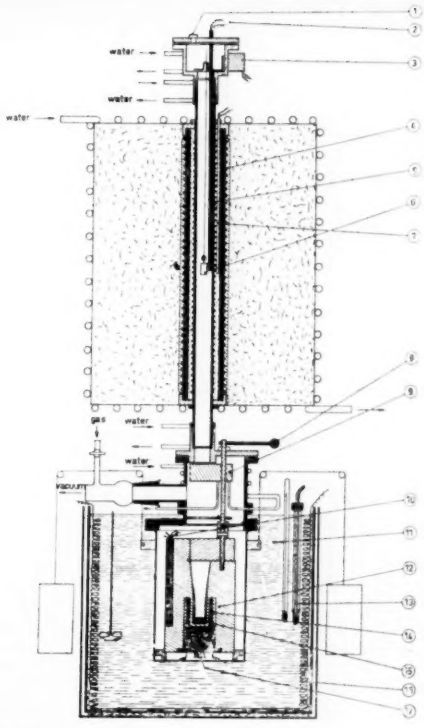
These enthalpy results show that there is not such a large discrepancy between aluminas of different sources and measurements made by different methods. The first measurements were done on pure solid and liquid silicon and presented, with the description of the calorimeter, in Boston last June. The silicon enthalpy is outside the subject of this discussion, but, speaking of iron, measurements on pure iron have just begun.

The specimen of iron (99·98% Fe) is put in a small cylindrical box of very thin and pure alumina which in turn is contained in a molybdenum capsule filled with ½ atm of helium and sealed. The furnace of the calorimeter is gastight and filled with a 20 mm pressure of argon. It is thus possible to avoid the contamination of iron by the atmosphere.

The work is now in progress but, unfortunately, the results are not sufficiently numerous to permit a comparison with Dr. Pattison's measurements and it is only possible to say that our figures are generally higher than the authors' and in better agreement with K. K. Kelley's compilation data. For example:

	H^T_0 cal/g	
	850° C	1000° C
IRSID	135·3	163·6
Kelley	135·2	163·8
Pattison	...	158·2

Mr. **I. Backhurst** (National Physical Laboratory): It is not at all easy, in measuring enthalpy by the 'drop' method, to secure any very high degree of accuracy, and the authors have managed to get one or two parts in a thousand for the standard deviation, which is commendable. The authors make an interesting comparison between the method of direct measurement of enthalpy and the adiabatic method of measurement of thermal capacity, and it should be realized that the two methods are to a large extent complementary. The 'drop' method gives the most accurate estimation of the enthalpy, provided of course that on quenching the specimen returns to the initial or a comparable state. But if, for instance, the mean thermal capacity over a range of 20° C is deduced from enthalpy values in the region of 1400 cal/g, measured to an accuracy of 0·1%,



1 Sight glass
2 13% Rh Platinum/Rhodium thermocouple for temperature measurement in the furnace
3 Electro-magnet operating the suspension clamp
4 Kanthal winding
5 20% Rh Platinum/Rhodium wire, wound on a mullite Morgan tube
6 Capsule containing the substance under investigation
7 13% Rh Platinum/Rhodium regulation thermocouple
8 Handle operating the gates
9 Water-cooled gate
10 Hole containing the thermistors for measurement and control
11 Water bath with controlled temperature
12 O.F.H.C. copper calorimetric block
13 Control thermistor
14 Calibration resistance
15 Copper cup containing chips of Wood's metal
16 Heating resistances
17 Orifice for the introduction of helium

Fig. B—Schematic cross-section of the apparatus

the error on the thermal capacity may reach about 10% or 20%. It will vary according to how close an approach to the thermal capacity is desired at a particular temperature.

If a curve is drawn of enthalpy against temperature, the tangent at any point gives the thermal capacity at that particular temperature. In practice it is necessary to take a chord approximating to the tangent, and the closer the temperatures determining the chord the greater is the percentage error in the corresponding thermal capacity. Consequently it is very difficult to get any very good values of the thermal capacity from enthalpy values unless the thermal capacity is changing only very slowly, in which case the tangent is very much the same as the chord, but if peaks or transformations are involved it is not so simple.

On the other hand, with a method such as the adiabatic one for measuring thermal capacity, there is considerable difficulty in getting satisfactory accuracy at high temperatures. If values are added to obtain the enthalpy, the errors will increase so that the enthalpy values deduced are less true than if measured directly. However, some of the errors balance themselves out and,

in any case, the resultant percentage error on the enthalpy cannot be greater than the maximum percentage error on the thermal capacity values. So these two methods are really complementary and, to gain the fullest and most accurate knowledge of the thermal constants, both methods should be used where possible.

For some time the National Physical Laboratory has tried to extend the adiabatic method to as high a temperature as practicable and, in fact, some years ago the thermal capacity of high-purity iron was measured up to about 1650° C. The values for latent heat were in general agreement, of the order of 64 or 65 cal/g, but the enthalpy values might be questioned because it was very difficult to ensure a uniform temperature over the whole of the inner enclosure.

To get the best from the ' drop ' method, the calorimetry at room temperature may be pushed to a high accuracy, but whether that is worthwhile depends upon the accuracy of determination of the temperature of the specimen when in the furnace. With the room-temperature calorimeter it has been found to be a considerable advantage to have the water in the calorimeter washing the lid, and generally the stirring was not really effective unless the stirrer was enclosed in a tube so as to push the liquid around. Thermometric lag can be reduced by using thermocouples or a small resistance thermometer instead of a mercury-in-glass thermometer. There again the authors seem to have secured very low values of standard deviation and it is doubtful whether there is much point in increasing the calorimetric accuracy.

Mr. **M. J. Hickman** (National Physical Laboratory): The errors in Dr. Pattison's calorimetry may be larger than he suspects. For example, as mentioned by Mr. Backhurst, it is desirable that the lid of the calorimeter should be washed by water, otherwise its use in temperature will be indeterminate and may vary in each experiment. It seems unlikely that a hot object can be dropped into water without producing steam which would condense on the lid and elsewhere, thus causing temporary local temperature rises. The variable heat losses that then occur may well increase with the initial temperature of the test sample. It is essential to ensure good mixing of the calorimetric fluid and this is best obtained by fitting the stirrer in a tube to give positive circulation. A transparent plastic model of the calorimeter enables this important factor to be studied.

Since the electrical heat input method does not reproduce the conditions of a test, it is desirable to check the equipment with a standard material of known heat capacity, such as alumina. Possibly this material was not available when these measurements were made.

Dr. Pattison, in introducing the papers, quoted two values for platinum which were in good agreement. In view of the wide discrepancies in heat capacity values did he believe that they were correct?

AUTHOR'S REPLY

Dr. **J. R. Pattison**, in reply, said: I would agree with Dr. Powell that some at least of the curvature shown in the plot of enthalpy against carbon content is due to a combination of experimental methods and also, it may be, some disagreement is due to the difference between quenching and slow cooling.

As regards the point made by M. Olette that my derived figures for pure iron are lower than those of Kelley and Darken and Smith, the reason is probably that I rejected more sets of figures than they did. In particular, I excluded all Umino's earlier results and did not use his later values above the melting point, whereas there are indications that Kelley, at least, gave weight to both sets of data in his calculations.

On the question of steam loss, we are confident that this was avoided by the calorimeter design, but I regret that we did not put a lid on the entrance tube for this would finally have disposed of the steam bogey. However, if an undetected steam loss would account for our results being lower than those of M. Olette, it is remarkable that Umino, who also used a water calorimeter, has produced the highest published values for total heat.

Several speakers have mentioned the calibration with alumina. After we got our results for pure iron, I wrote to the U.S. National Bureau of Standards asking for a sample of this alumina. Unfortunately, my letter must have gone to the wrong department, for the alumina which I received was a very light, loose powder, a most intractable material and not at all convenient for calorimetry. I shall make a further application and hope that this time I will obtain some of the material used by Ginnings and Corruccini, which I understand to be in a more granular form.

The results given by M. Olette for alumina and iron are most interesting. The only way of resolving the differences between our results is by comparison with the standard alumina used by the U.S. National Bureau of Standards, which we hope to accomplish as soon as possible.

The reason for my statement that the metal-block calorimeter was unsuitable for electrical calibration was that the temperature rise is produced by metallic conduction at a lower rate of heat transfer than by liquid convection, and there is a great possibility of asymmetrical heat flow with differences occurring between the two cases of a hot specimen and a heated coil.

Dr. Powell and Mr. Backhurst indicated the aims of their organization. The N.P.L. is concerned with fundamentals while B.I.S.R.A. is concerned with obtaining data to be used in subsequent calculations for heat balances in metallurgical processes, and these do not need to be of an extremely high accuracy. In other words, at B.I.S.R.A. we are interested in total heats and mean values of specific heats, assuming that they are constant between transformations, rather than the true specific heats required by the N.P.L.

Mr. Hickman suggested certain possible errors in the calorimeter due to variations in stirring and the air space below the lid. If such variations occurred markedly from experiment to experiment they should have been indicated by the standard deviations for the various regression lines.

A difference between the two processes by which heat is communicated to the temperature-measuring device from a hot specimen or from a calibration electrical heater can be a source of error in any type of calorimeter. Here, a check with alumina as a standard may be informative.

For the enthalpy of platinum, there are two sets of figures which agree very well, and perhaps they are both wrong; but we must believe in something and in making a small correction for 0·4 g of platinum, no sizeable error can be introduced.

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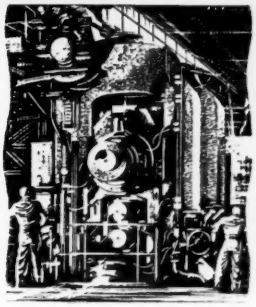
IRON AND STEELWORKS ENGINEERING

The Iron and Steel Engineers Group



Report of the 32nd Engineers Group Meeting

The THIRTY-SECOND MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1. on Wednesday, 5th December, 1956. Major W. R. BROWN, D.S.O., was in the Chair for the MORNING SESSION.

At the MORNING SESSION a paper by Messrs. F. J. POTTER AND L. DUFFY entitled " Blowers for Use in Iron and Steelworks ", which appeared in the November, 1956 issue of the *Journal* (vol. 184, pp. 331–347) was presented and discussed. A report of the discussion is given below. The discussion at the Afternoon Session will be published in a later issue.

BLOWERS FOR USE IN IRON- AND STEELWORKS

Mr. **L. Duffy** (C. A. Parsons and Co. Ltd.) presented the paper.

Mr. **C. Ungoed** (Steel Company of Wales Ltd.): Messrs. Potter and Duffy have presented a very interesting résumé of the present practice of blast-furnace blowers, but throughout this paper it appeared to me that there was a bias in favour of the centrifugal blower at the expense of the axial type. I think it necessary somewhat to redress the balance.

In the iron and steel industry any type of plant which shows a gain in efficiency and a reduction in running costs always merits very close examination. The difference in overall efficiency between the axial and radial types is quoted as between 5–7%, and while it may be conservative, it represents an annual difference of about £30,000 in the running cost of a modern high-duty blast-furnace.

Some more detailed comparisons of the efficiencies of these machines would have been informative, particularly if shown as lines of constant efficiency on the pressure/volume characteristics rather than isolated points. Superimposing the pressure/volume resistance curve of a typical blast-furnace on these characteristic curves would immediately show that the area of maximum efficiency of the axial compressor approximates far more closely to this curve than does its centrifugal counterpart.

Would the authors quote the best efficiencies of:

(i) A variable speed centrifugal compressor with and without diffusers
(ii) The variable-speed axial-flow compressor
(iii) The more recently developed axial/radial mixed-flow compressor.

The Company with which I am associated has operated a large axial compressor during the past year. Comparisons of this machine and the previously installed centrifugal compressors are summed up as follows.

Advantages of the Centrifugal Compressor—It is relatively simple and straightforward in construction tending to keep down its capital cost. The pressure/volume characteristics are such that wide variations in volume demand can be met at constant pressure. This was formerly a great advantage in earlier blast-furnace operation as the volume required varied within wide limits, whereas the blowing pressure range was comparatively narrow. Should the volume and pressure requirements of the machine inadvertently approach the surge limit the output cannot be stalled.

Disadvantages of the Centrifugal Compressor—The main disadvantage is comparatively low efficiency. The addition of inter-stage diffusers can recover some of the lost energy by raising the overall efficiency by about 5% but correspondingly it reduces the operating area on the pressure/volume characteristics. It is also impracticable to vary the pressure/volume characteristics from the original design as sometimes may be required by changes in furnace blowing techniques. The compressor output is limited by design reasons to 120,000–130,000 ft^3/min.

Advantages of the Axial Compressor—The axial-flow compressor has the advantage of small physical size, and high efficiency with corresponding saving in blast-furnace blowing cost. It is capable of a very high pressure ratio which appears to match the requirements of the modern blast-furnace. Subject to the correct design of the machine, all normal blowing can be supplied at

points on the pressure/volume characteristics all of which are in the area of maximum efficiency. Changes in furnace design or operating technique may require major changes in blowing characteristics, but re-blading the compressor to match these new demands is a comparatively simple and straightforward job.

Disadvantages of Axial Compressor—The axial compressor is a very highly developed machine and the design and construction is therefore very expensive. The narrow volume range is a disadvantage when precise information on its operating duty cannot be forecast. Blades are more subject to erosion in some installations and inlet air filters have been thought necessary, and dust build-up can alter the operating characteristics to an appreciable extent.

To summarize the merits and demerits of each type of furnace blower: both are capable of satisfactory operation, but to achieve the large financial savings possible with the axial machine, the close co-operation of the blast-furnace management is essential to narrow the blower operating duty to within its optimum range.

Mr. **Duffy:** Mr. Ungoed has raised some interesting points about the axial-flow blower and we are indeed pleased that the iron and steel industry has taken an interest in this type of machine as a possible solution to its blower requirements.

When we introduced the paper we did not in any way intend to favour either the axial-flow or centrifugal blower. We gave a paper which we thought was suitable for the steel trade, and we had at the time the impression that steelworks operators themselves favoured the centrifugal blower.

It was suggested that an advantage of the axial-flow machine was its smaller physical size, but this is not quite true. It must be remembered that the axial-flow blower has to pass the same quantity of air as its centrifugal counterpart, and if similar velocities through passages and branches are maintained they must both have practically the same physical dimensions.

Figures 11 and 12 in the paper show two blowers of similar capacity. Figure 11 shows a centrifugal blower designed for 160,000 ft³/min against an outlet pressure of 35 lb/in² gauge. The overall length from the coupling to the outboard end is 24 ft 6 in. and the overall width is 10 ft 9 in. Figure 12 shows an axial-flow unit to deal with a similar quantity against an outlet pressure of 25 lb/in² gauge and the overall length is 19 ft 4 in. To increase the outlet pressure of this machine to 35 lb/in² gauge would mean an increase of about three stages which would add at least 18 in. to the length of the unit. The difference in length therefore between the axial and centrifugal designs is about 3 ft 6 in., and as the width of the axial unit is 12 ft 4 in. compared with 10 ft 9 in. width of the centrifugal unit, little difference in physical size can be claimed.

The statement that the axial-flow machine is capable of a very high pressure ratio is somewhat misleading. A centrifugal unit can be designed to meet pressures far in excess of pressures likely to be required in blast-furnace work, and both types of machine are limited in pressure ratio only by the economic size for which both blades and impellers can be manufactured.

It has been suggested that an advantage of the axial design is that the blower characteristics can be altered comparatively simply by changing the blades, but it must be borne in mind that the blading is the most expensive item of the axial-flow blower and that the driving unit would also need re-designing or renewing.

We are ourselves keen on the use of an axial-flow machine as a means of blowing, and do not in the least mind whether an operator prefers a centrifugal or an axial-flow unit. The centrifugal machine has proved in the past to be a robust machine on which maintenance requirements are very low. Experience with the axial-flow unit is at present limited, but we are indeed pleased that the Steel Company of Wales has taken up this type of design, and we shall wait with interest to hear the results of their operating experience and also the maintenance costs.

The axial-flow unit is definitely susceptible to blade resonance which can occur from periodic excitations, and these can cause fatigue fracture of the blade. If the flow volume is large, blades can be designed to withstand these excitations and vibrations and I would say that the axial-flow blower becomes an economic proposition when the volume exceeds about 120,000 ft³/min. Below this volume, I imagine, the centrifugal blower will continue to hold its own in the iron and steel industry.

I was asked to compare efficiencies between a centrifugal unit with vaned diffusers and a centrifugal unit with vaneless diffusers. A vaneless diffuser can be arranged and adapted to suit the required flow-rate so that exactly the same efficiency as a vaned diffuser may be attained at the optimum design condition. However, at volumes other than the optimum the vaned diffuser is much less efficient in the choking region which is the large-volume end of the curve, and much more efficient towards the surge.

Figure 4 of the paper shows both vaned and vaneless diffuser P/V curves. At 100% conditions the efficiencies are practically the same. At maximum volume the vaneless diffuser machine is about 8% higher in efficiency as compared with the vaned diffuser, but at maximum pressure conditions the vaned diffuser machine is about 5% higher than the vaneless diffuser.

Mr. **C. E. Sayer** (McLellan and Partners): I would first comment on the last two paragraphs on page 334, the first beginning "In both axial-flow and centrifugal . . ." and the second beginning "The total energy of the gas . . .", which I found a little confusing. The beginning of the first seems to indicate that what follows is intended to be common to both types, but subsequently the text reads as though the references are to the centrifugal type. It is also not clear to what extent they refer to a single stage of either or to a complete blower.

The authors distinguish between three parts: (*a*) the guide means, (*b*) the runner, and (*c*) the diffuser, and they refer to these as "in each stage", but it is difficult to dissociate the guide means from the diffuser in an axial-flow stage, because in a sense the two things are merged into one.

I would also question whether the word 'therefore' is needed in the sixth line of the second paragraph.

On p. 339 there is a reference to anti-surge devices from which it might be thought that such devices are always impulsed by volume and pressure, but they can equally be impulsed by volume and speed, and at least one continental maker uses this combination. The surging point can be related to volume and pressure, or volume and speed, and the device can be controlled by an impulse from the pressure at the blower outlet or the speed at which the blower is running for a certain volume.

The description of the 'split-wind' blowing system is very interesting, but the authors refer to this new large blower as being in a sense a booster. Surely that is hardly a correct term because this supply of air from the large blower is acting in the sense of a parallel supply to the supply from the older blowers on which the furnaces used to depend.

The large blower is apparently maintained at constant pressure and volume and runs as a base load machine. Assuming that all its output of 160,000 ft³/min is absorbed and that each of the four furnaces is taking

air from it at the same rate of 40,000 ft³/min, surely the reduction in the demand on the old blowers must be so great as to bring them nearly to surge point, since they must be working at the same pressure as before. Has there been any modification of the old blowers to enable them to deliver less air with, if anything, a higher pressure?

On p. 342 the authors say they know of only one modern axial-flow blower in use in the U.K. I assume that they mean the blower on the large furnace at Margam. There are in fact two others in use in South Wales, of a different make from that at Margam. One of them has been in use for nearly 12 months, the other for the last three or four months, and both have so far given extreme satisfaction. They are serving 18-ft furnaces and are designed for 55,000 ft³/min at 18 lb/in², with a pressure capacity up to 25 lb/in² and a most efficient design point of 47,500 ft³/min at 17 lb/in². Their speed range is 3050–5800 rev/min. The experience to date has been that the anti-surge valve has been used very infrequently and then only to a small extent.

An interesting point is that these two machines have hand-operated suction throttling valves, but their only purpose was to enable conditions to be obtained in what I might call the bottom left-hand corner of the area to the right of the surge line below 5 lb/in² for blowing-in, which otherwise would mean running the blower at below the minimum speed. There are usually both top and bottom speed limits, having reference to the first and second critical speeds. The authors suggest that the centrifugal blower can be made to equal the axial-flow blower in respect of pressure capacity and seem to imply that speed can be increased to any degree necessary to bring them into line in this respect, but there must be a limit set by either the first or the second critical speed.

Reference is made on p. 344 to my paper on the gas-turbine-driven blower in which I stated that there is little gain in efficiency from the straight gas-turbine-driven blower without the inclusion of blast heating as an integral part of the gas-turbine cycle. This statement taken out of its context might be interpreted rather more widely than I intended. It was based on a comparison between steam plant employing moderately high steam conditions and gas-turbine plant with an inlet temperature limited to 1200° F or thereabouts. It is also now about two years since I wrote the paper and improvement in gas-turbine technique and efficiencies during this time must be borne in mind.

Where there is a large demand for steam, as is usually the case in steelworks, and where there are other means of providing the required flexibility in steam supply, the idea of installing gas-turbine drives with exhaust boilers also merits consideration. As an instance, where the turbine itself is exhausting at 700° F and reaching a final exit temperature of about 400° F or even lower with a boiler, the combination has appreciably higher thermal efficiency than the gas turbine with exhaust heat exchanger having a final exit temperature (determined by the temperature of the compressed combustion air) perhaps 100° F higher.

The authors say that electrically-driven blast-furnace blowers are seldom used. They are, in fact, quite common in Europe. There the tendency seems to be to sell blast-furnace gas to a local electrical generating concern in the area of a group of works, and to drive blowers electrically.

The caption to Fig. 13 on p. 345 reads " Comparative pressure/volume characteristics for axial-flow and centrifugal blowers designed for same normal duty ", and surely should have contained the word " typical ". To some extent one can vary the characteristics of both types by changes in design of blades or vanes, and the degree of steepness of the characteristics of an axial-flow blower, in particular, can undoubtedly be varied by blade changes with some small sacrifice of efficiency.

On the subject of initial cost my experience is that tenders on similar specifications can quite well be slightly in favour of the axial-flow blower. Referring to Mr. Ungoed's remarks I strongly support his reference to the greater pressure reserve of the axial-flow design and in doing so, I differ from Mr. Duffy's reply to Mr. Ungoed. Having regard to maximum speed in each case, the axial-flow blower has a great advantage in reserve of pressure and, moreover, in the ability to draw on a higher pressure with very little loss of volume. By the very virtue of those steeper characteristics, provided there is sufficient power in the turbine, it is possible to run up to a higher pressure with much less loss of volume than with a centrifugal blower. This facility has been amply demonstrated on the two machines to which I have referred and has, I know, been found of great value.

Mr. **Duffy:** I shall attempt briefly to reply to some of the points raised by Mr. Sayer. On p. 334 we were referring only to a single stage. There must always be some method of guiding the air to the impeller, irrespective of whether the impeller be radial or axial and we always refer to this as the guide means, and after the impeller there is always some type of diffuser. A stage therefore consists of the guide means, the runner, and the diffuser. Admittedly the diffuser of an axial-flow stage serves a dual purpose, being a diffuser after the runner and also a guide to the succeeding stage. In a centrifugal stage the guide means is an individual passage with each stage.

I think the sentence on p. 334 which begins " It is an advantage therefore to have a large part of the total head . . . " is quite true. With a centrifugal machine, manufacturers have adopted an impeller with backward-curved vanes with the majority of the work per stage done in the impeller itself and very little in the diffuser. Axial-flow machines have been developed with 80–100% reaction blading which means that between 80 and 100% of the pressure increases takes place in the rotor blades and only up to 20% in the stator blades.

The expression ' booster ' blower referred to in the description of the ' split-wind ' blowing system may be a little misleading. The large blower is in fact working in parallel with the existing blowers. The term ' booster ' perhaps crept into the early discussions on the design of this machine when we were asked to look into the possibilities of ' boosting ' the air supply to each furnace. The existing machines at Appleby-Frodingham are each capable of 80,000 ft³/min at 30 lb/in² gauge, and it is not their intention to reduce the flow rates from these old machines. The increased capacity available from the new machine is required at the furnaces to increase output.

We are indebted to Mr. Sayer for the information with regard to other axial-flow blowers which are in existence in south Wales, and it is interesting to learn that this type of machine has been installed for blast-furnace blowing for flow rates as low as 47,500–55,000 ft³/min.

Replying to the point about greater pressure reserve with axial-flow units, I still maintain that it is possible, with similar limiting-stress factors and shaft power available, to design both types to give the same maximum pressure. The difference in characteristic of both machines, however, makes for a great change in speed with a centrifugal unit for a given increase in pressure at a constant flow rate.

The curves shown in Fig. 13 are typical of our blowers of both centrifugal and axial-flow design.

For a number of years now the possibility of using gas-turbine drives in steelworks has occupied the minds of engineers, and we are most interested to have some further information from Mr. Sayer on this problem. We have ourselves in the past carried out a number of design projects on steelworks plant using gas turbines and heat exchangers, but find that they are still out of favour.

Mr. **L. S. Lindsay** (Steel Company of Wales Ltd.): This paper has been most interesting and instructive to me, from the point of view of past and present blower operation, but in my opinion it does not pay sufficient attention to future trends. I feel that more attention should be given to efficient operation as well as reliability. In these days of fuel shortages with ever increasing costs we must be more efficiency-conscious than ever before. When planning new plant installations, next to reliability, efficiency must be the deciding factor in our choice of machines and thermal cycles.

The centrifugal blower has given us satisfactory service for many years and proved to be a most reliable machine, but it is not the most efficient machine on the market to-day. Therefore, we must look elsewhere if we hope to reduce fuel requirements and of course operating costs. In recent years, the axial-flow blower has been developed and it has been claimed that improvements in efficiency of the order of 10% at design point have been obtained. In view of the large gains in efficiency claimed, this type of machine must be seriously considered for future blast-furnace blowers.

Axial-flow blowers have now been in continuous service for as long as 10 years and have proved to be most reliable mechanical units. The aerodynamic structure of the blades has been thoroughly investigated and stage efficiencies of 92–93% are now not uncommon. Also, by increasing profile thickness blades are not now subject to damaging vibrations which in the early days were experienced, nor are they subject to loss of efficiency due to change of profile caused by erosion. Sufficient knowledge has now been gained to ensure that no resonance vibrations are set up with the natural excitation frequency of the machine.

The steep pressure/volume characteristic of the axial-flow blowers has one strong advantage: for blast-furnace operations it provides a high pressure reserve. Thus for a small increase in volume there is a correspondingly high rise in pressure to meet changed furnace conditions.

The authors have referred to the expense of the precision-engineered aerodynamic fixed and moving blades and suggested that this is prohibitive. In practice this is not so; new fixed and rotating blades together with diffuser and modifications to fixed blade carrier can be supplied for about 40% of total cost of the compressor blower. Thus the characteristics of the blower can be easily altered to suit changed blast-furnace operating conditions.

It must, however, be stressed that with the steep pressure/volume characteristic, axial-blower designers have not as much room for error as with centrifugal blowers, and, to ensure that the blower operates in the correct zone, the blast-furnace staff must be prepared to state their exact blowing requirements in the early days of design.

With this search for improved efficiencies we should couple the search for more effective control giving more flexibility with larger operating areas. Possibly some form of moving surge-line control by means of recuperative turbines and perhaps the inlet throttle control. In my opinion, these additional complications would not have any effect on the reliability of the machine, but would of course require a rather more intricate control system.

In conclusion, it would be interesting to have the authors' views of the future of gas turbines for driving blast-furnace blowers, with reference to the improved cycle efficiency and possible saving in the overall capital cost by reducing the number of Cowper stoves.

Mr. **Duffy:** The axial-flow machine appears to be getting popular. We shall have to amend our ideas, as in the past we have had the impression that in steelworks the majority opposed the use of axial-flow blowers.

We are not opposed to this type of machine and I hope we have said nothing in the paper to suggest that we are. It has all the advantages enumerated, but I still maintain that the most expensive part of the axial-flow machine is the blading, and it is wrong to imagine (although I have heard this stated elsewhere) that it is a simple operation to scrap the blading and start again.

When designing a blower to supply the blast air to a specific furnace it is always difficult to find out from literature, and even from talking to blast-furnace operators, the type of pressure/volume characteristic best suited to the furnace requirements. If the characteristic which the furnace really requires is constant volume, then the axial-flow blower would seem to have an advantage over the conventional centrifugal blower. However, furnace operators, to overcome certain undesirable furnace conditions, find that whilst working on maximum pressure control will achieve the best results on one day, on another occasion with similar furnace conditions the best results are achieved by working on maximum volume control. With furnace conditions apt to change frequently, blowing plant can seldom be installed to meet an ideal condition and it would appear that a blower which will operate efficiently under normal operating conditions and also give economically a wide range of flexibility is required for the supply of blast air.

I do not think there is much difference in price between axial-flow and centrifugal blowers and the choice of machine is purely a question of the furnace operator being satisfied that the blast requirements of a furnace are adequately covered.

With regard to gas turbines for driving blast-furnace blowers, a paper* by Mr. Sayer published a short time ago in the *Journal* covered the use of the gas turbine in steelworks and dealt much more thoroughly with the subject than I can hope to here.

Mr. **R. Lord** (Steel Company of Wales Ltd.): The meeting has developed into a debate between the authors and the Steel Company of Wales on axial-flow blowers.

I would like to give a few facts and figures from experience over the last year of operation; to the majority of people it will probably serve as a better argument for an axial-flow blower.

The unit we have working is a 16,000-h.p. turbine driving a blower of 125,000 ft³/min at a maximum pressure of 35 lb/in². We have never yet used this pressure or capacity, the usual rate is in the order of 95,000 ft³/min at 28–30 lb/in².

Much has been said about the surge line but nothing about the temperature conditions at the blower inlet. Superimposed on Fig. *A* are two conditions of 70° and 50° F giving a difference of 3 lb/in² on the lower scale and 1 lb/in² on the highest scale. This can be the means of great saving of steam when working on a very stiff furnace operating, as we are, near the surge line.

Another difficulty has been the very frequent jumping of the furnace (every 20 min) which has made the use

*C. E. SAYER: *J. Iron Steel Inst.*, 1955, vol. 179, pp. 359–371.

of the auto-volume regulator impossible. When working on the auto-volume regulator it has the advantage of the difference of the vertical component on the volume line against the angular component of the space line, this difference is as much as 1 lb for any given volume.

Some typical consumption figures are: 25 lb/in², 90,000 ft³/min, 59,000 lb/h steam, which are very similar to those of a centrifugal blower.

Mr. **Duffy:** It is interesting to have output figures quoted by the Steel Company of Wales in connection with their axial-flow blower, but the steam consumption figures given are difficult to compare with those of a centrifugal unit without knowing the working pressure and temperature of the steam.

The condition whereby a blower performance is better in winter than in summer applies also equally to a centrifugal unit. With a blower running at constant speed the discharge pressure for a given flow rate is dependent upon the air intake conditions. In the relationship

$$\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = \frac{T_2}{T_1}$$

$T_2 = (T_1 + \Delta t)$, and Δt is a function of the peripheral speed of the impellers and the air velocities through the impeller channels, which remain unaltered for the conditions state above. From this it can be seen that with an increase in inlet temperature T_1 the ratio P_2/P_1 is reduced, and with a reduced value of T_1 the pressure ratio is increased whilst the power at the blower coupling for a constant volume of flow is inversely proportional to the intake air temperature.

Mr. **A. R. Jones** (Guest Keen Iron and Steel Co., Ltd.): I was particularly interested in the 'split-wind' and double-flow technique and its future effect on blast-furnace operation. Likewise, constant-pressure and constant-volume control appear to have great possibilities.

On the question of axial-flow and radial-flow, it is agreed that the radial-flow blowers are of robust construction, reliable, and give many years of useful service but with the present demand for fuel efficiency, blower efficiency, and furnace efficiency any alternative which can give improved conditions and lower maintenance cost must be examined.

At Cardiff, my company has installed two axial-flow blowers during the last 12 months which have given satisfactory results. They have been trouble-free and the working characteristics match the furnace conditions very well. Normal operating conditions are well above the surging limit and the anti-surging devices seldom come into operation.

Erosion and fouling which may take place due to dust or other foreign matter in the axial-flow blower should be considered. At Cardiff, cellular-type air filters impregnated with oil and mechanically operated for self-cleaning are used. Opening up the blower after eight months' continuous operation indicated a minute film of dirt, almost of graphite consistency, on the blading; no erosion or fouling had taken place, which indicated the success of this method of air filtering.

It is most important that the blast-air delivery non-return valve should be situated in the blower house, for in the event of its failure to close automatically manual means can quickly be applied and so prevent the set running in reverse, which may cause the oil to run out of the bearings and possibly do serious damage.

Mr. **Duffy:** The axial blower for use in ironworks has not proved popular, either in the U.K. or in the U.S., but a number have been supplied in Western Europe.

A disadvantage of the axial-flow blower when compared with the centrifugal type is the very steep pressure/volume characteristic and narrow working range, and until furnace operation is such that uniform blast conditions can be maintained, the economy in fuel achieved by installing an axial-flow blower is likely to be very limited. The efficiency falls off considerably with a flow volume slightly less or greater than the optimum for a given speed of rotation, and with the reduced working range it is almost certain that for some period of the blow an anti-surge device would have to be in operation to maintain steady flow, which introduces a further loss in efficiency.

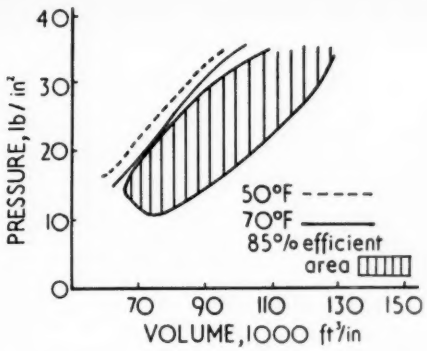


Fig. A—Output P/V relationship at two air inlet temperatures

That the blower characteristics match furnace conditions contributes much to the success achieved by the axial-flow blowers recently installed at Cardiff, and therein lies the secret of success in the use of this type of blower.

We agree that some sort of air filter is required to prevent erosion and fouling of blades due to dust and other foreign matter. We have had similar experience to that of Mr. Jones in connection with the axial-flow compressors of our gas turbines. After opening up we have found this fine oily dust on the blades. Provided the machine is opened up sufficiently often and this deposit is not allowed to accumulate, the efficiency can be fairly well maintained.

The non-return valve is often neglected and left undisturbed for long periods. This valve has to disconnect the blower from the system and prevent the set from running in reverse when changing the blowing of a furnace from one blowing unit to another. It must also isolate the blower from the blast main in an emergency (for instance, when the power supply to the driving machine fails, or in the event of an explosion in the mains) to prevent damage to the blowing unit. It is advisable to locate this valve inside the blower house so that its operation (e.g. ready oscillation of the valve during service) can be observed from time to time. This also facilitates dismantling during overhauls, and it is less likely to be overlooked than if the valve, as is often the case, is located at some inaccessible point outside the building.

Trouble was experienced on one of our blowers in South Africa in changing the blowing of a furnace from one machine to another. The non-return valve of the first machine stuck in a partially open position and it was not until some time later, when someone on passing the machine noticed the shaft was still revolving, and realized that the blower was motoring the turbine in reverse. Fortunately it was brought to rest before too much damage was done, but not before the bearings had been wiped.

Dr. **H. R. Mills** (B.I.S.R.A): In the past I have found difficulty in getting a trustworthy comparison between axial-flow and centrifugal blowers. The reason is that the centrifugal blower has been designed for some years to suit the blast-furnace, and the designer has tried to produce something with a very wide working range and reasonable efficiency. The axial-flow blower has been developed by the makers of gas turbines, who have taken the opposite attitude and tried to get the highest possible efficiency without much regard to the range of working. Consequently, the curves normally published for these two types of machine are not comparable. Is it correct to assume that the two curves in Fig. 13 both apply to machines designed for ironworks use? From the paper I gather that both machines were designed by the authors' firm, in which case the authors probably believe that each represents the best compromise between efficiency and range of operation.

Surging is the main trouble with an axial-flow blower. From the curves given, it seems that the volume could be reduced, at the same pressure, to about 80% before surging occurred. An investigation carried out a few years ago showed that steelworks often ask for a bigger range of working than they need for a blast-furnace and that this drop of volume from 100 to 80% is sufficient for most of the working time. Seldom would there be a greater drop provided that an accurate estimate of the normal working point had been made. Fortunately, the general tendency is to under-estimate the volume required, and the advances which have taken place in ore preparation and blast-furnace blowing techniques have been such that blast-furnace men are finding that they can blow more air into a furnace than they thought when the blower was first ordered. That means that surging troubles will probably not be serious.

It is difficult to get a good basis of comparison for the driving of blowers. The authors have said that little gain in efficiency can be expected from a straight gas-turbine-driven blower without the inclusion of blast heating. The efficiency of a steam turbine covers a very wide range, according to the working pressure and temperature and to complications added in the form of feed-heating arrangements. In the same way, the efficiency of the gas turbine varies over a wide range, according to the turbine inlet temperature and the money that may be spent on a heat exchanger. The only fair basis of comparison of efficiencies is to take two plants with similar initial costs. On this basis, do the authors consider that the efficiency of the gas turbine would be higher or lower than that of the steam turbine? All costs must be considered, for the gas turbine replaces not only the steam turbine but also the associated boiler and water-treatment plant.

For some years now we have been considering the possibility of blowing and heating by the same plant, using a gas turbine. The advantages of this would be as follows. Greater efficiency is attained if the two are combined, for the heat loss which would normally occur from the heating plant is re-absorbed into the system and used in the gas turbine. Secondly, there may be an advantage in capital costs. That is less certain because it is difficult to know the capital cost of a gas-turbine plant until one is completely designed. Another advantage of a combined blowing and heating system is that it would avoid surging of the axial-flow blower. Combined together in one unit are the blower to provide air for the blast-furnace and the compressor which is an integral part of the gas turbine. With this combination, considerable variation in the requirements of the blast-furnace may be tolerated without running back to the surge line.

However, there has been some trouble in introducing the system. When it was first proposed about four or five years ago, by the pioneering firm, the temperature on which they were working for the blast was 650° C, which at that time seemed to be the highest temperature generally in use. In those conditions, I think there is no difficulty in designing the heat exchanger for heating the blast.

Requirements were increased to 750° C to take account of improvements which might take place in blast-furnace blowing. Now, 750° C is a little difficult; there are a number of heat exchangers running at 700° C, but 750° C is getting beyond present experience. Nevertheless, a number of tenders were received for heat exchangers to put the blast up to 750° C. By the time this was done, however, four years had elapsed; and some blast-furnace engineers are now using 750° C and a few even more. We have been advised that it would be unwise to pursue the scheme unless at least 900° C can be reached. The number of works that will put their blast temperatures up to 900° C in the next ten years is problematical, but the figures seem to be going up rapidly. The authors mentioned that the experience to be gained on the nuclear power stations with high-temperature heat exchangers might help in these developments, but will the heat exchangers they have in mind be running at temperatures as high as 900–1000° C?

Mr. **Duffy:** The curves for the axial-flow and centrifugal blowers shown in the paper were actual curves of machines designed solely for ironworks' use and show performance curves typical of machines of my firm's manufacture.

For equal capital cost, a straight gas turbine with heat exchangers would probably be more efficient than a steam turbine, but at the present time the difference would be marginal and not sufficient to justify the change. It should be pointed out that a gas turbine designed to burn a low calorific value gas, such as blast-furnace gas, will be less efficient than a normal gas turbine because of the large amount of power required to drive a gas compressor which will inevitably be less efficient than the main gas-turbine compressor, and which must compress more gas than is actually burned in the combustion chamber, to provide a margin for control purposes.

The gas turbine must not be regarded simply as a more modern substitute for the steam turbine, but must be integrated into the steelworks so that its special qualities are utilized. The main attribute of the gas turbine, apart from its simplicity, is its high-grade waste heat. This can be used to raise steam, which is always required in a steelworks, or for heating the blast air. This latter may be done either by the combined cycle mentioned by Dr. Mills, or by simple use of the exhaust of a non-recuperative gas turbine with reheating to heat conventional stoves.

The former arrangement has the advantage of great flexibility as regards the pressure/volume characteristics, but it does introduce difficulties when the blast temperature exceeds 700–750° C and is rather a complex machine to control.

The latter arrangement has no restriction on blast temperature, but with present gas turbines the quantity of exhaust gas is greater than that required to heat the stoves. This is aggravated by increase of blast pressure and mitigated by increase of blast temperature. The excess gas may, however, be used to raise steam or to heat the blast from existing steam turbine or electrically-driven blowers.

The nuclear power stations are of too modern design to answer the question asked, but it is expected that the working temperatures and pressures of the heat exchangers will advance rapidly in the near future.

Mr. **C. L. Reid** (John Lysaght's Scunthorpe Works Ltd.): In the discussion relating to the comparison between centrifugal and axial-flow types of turbo-blowers, consideration has been given to plants where three or four similar blast-furnaces are in operation. Many steelworks, however, have to deal with varying sizes of furnaces, which factor invariably decides in favour of the centrifugal type of machine owing to the limited effective range of working of the axial-flow type in spite of its improved efficiency.

Reference has been made to difficulties in the design and the corresponding maintenance difficulties of the axial-flow type. As those involved in both manufacture and maintenance normally deal with turbines as well, it would seem that this point does not arise.

Mr. **Duffy:** In the earlier discussion it appears to have been overlooked that steelworks often have a number of furnaces of different sizes. As steelworks grow, larger furnaces are built and when a new blower is ordered to suit a new furnace the engineer has in mind that the occasion may arise when the new blower may be required to blow a much smaller furnace, and it is often only the centrifugal blower that is capable of meeting this wide range of operating conditions.

Though it is true to say that those involved in both design and maintenance of axial-flow blowers also normally deal with turbines, there is a fundamental difference in the flow conditions prevailing in both types of machine. The operation of compressing a fluid and maintaining a pressure gradient, which in general opposes the flow, is far more sensitive to profiling than the opposite operation of expanding or accelerating, and it is therefore essential that examination and cleaning of the blower blades be carried out at fairly frequent intervals.

Mr. **D. R. Brown** (Ashmore, Benson, Pease and Co.): The attitude expressed to-day that, if a blast-furnace manager knows the wind his plant requires, then a blower can be built to meet his needs, is too complacent. Furnacemen require an increasing flexibility both as regards volume and pressure from their blowers and this trend will continue, for the modern large furnace can be operated economically over a very wide blowing range.

To illustrate this let us consider the possible needs of a large furnace, similar to the latest Seraphim units, that might be installed in a new plant. In stage *1* of the first campaign, we assume that a wise management has built a furnace with plenty of spare capacity and the works demand for iron might only warrant a blowing rate of 65,000 ft^3/min at 15 lb/in^2. In stage *2*, the Company prospers and more iron is needed for more steel; the furnace is blown a little harder at 80,000 ft^3/min and 25 lb/in^2. By stage *3*, the ore preparation is built and the sized burden permits consistently blowing 100,000 ft^3/min at 27 lb/in^2. In stage *4*, capital is available to further prepare the burden and the charge is 100% sinter resulting in a demand from the blowing plant of 130,000 ft^3/min at 32 lb/in^2.

This is not an exaggeration of future needs, for blast-furnace operators in the U.K. (and, I believe, in the Soviet Union) have operated a furnace right through this range; furthermore, they have found its charging equipment and all other engineering features capable of this flexibility.

I suggest therefore that the blower can only be said to match the furnace and meet the furnacemen's specification, when it covers a similar range. I do not expect the answer to-day, but I would ask the designers to consider this aspect for the need exists, and the U.K. must continue to offer the best equipment in the world. Should we perhaps consider 'split-wind' blowing, or can a blower and its turbine be constructed so that additional stages can be added to keep pace with the furnacemen's rapidly increasing ability to smelt iron?

Mr. **Duffy:** The discussion this morning has developed into a debate on axial-flow versus centrifugal blowers and though at present efficiencies at the optimum design duty can be attained with axial-flow blowers which surpass those of the centrifugal blower, it is advisable carefully to compare the merits and drawbacks of the two types in each individual case.

Mr. Brown has given a very comprehensive specification covering the blast requirements likely to apply to a furnace over a number of years of service. A curve is shown depicting P/V characteristics typical of axial-flow and centrifugal blowers designed to cover the range of operation quoted (Fig. B). A single unit capable of this flexibility is not an economic proposition as all ancillary equipment would have to be designed to meet the ultimate maximum duty. During the initial working periods large items of plant would have been installed, entailing considerable capital expenditure upon which little return could be expected until after the complete plant was in its final stages of operation.

When considering blowing plant for a volume range of 65,000–130,000 ft^3/min at pressures from 15–32 lb/in^2, the best solution appears to be to design two machines each capable of delivering 65,000 ft^3/min to 32 lb/in^2 gauge, and install initially boiler plant and equipment to suit one blowing unit, and this unit would meet the blowing requirements of stages 1 and 2. At some future date the original blowing equipment could be duplicated and with both units working in parallel stages 3 and 4 would be adequately covered.

In the above proposal only one furnace has been considered, but when considering two or more furnaces working through similar stages of development, 'split-wind' operation similar to the Seraphim plant offers the most economic installation.

Mr. **G. R. Ward** (John Lysaght's Scunthorpe Works Ltd.): Mr. Brown raised many interesting points with which I agree, particularly on the flexibility of blowers.

Blast-furnace operators have been told that they must produce an extra 7 million tons of pig iron by 1962. Much of this iron will be made by new units, but all existing units will have to increase their production. This has been made possible by improved ore preparation, high sinter burdens, high top pressure, and increase in the size of existing furnaces. Too many operators cannot take full advantage of these improvements because of limited blowing facilities.

Blowers which were designed only to give present outputs will not contribute much to increased production. Where new blowers are to be installed, there should be all possible flexibility in specification, to allow for further improvements in furnace operating techniques.

Blast-furnaces in the U.K. are using increasing temperatures of the blast up to 900° C, and temperatures in Germany, the Soviet Union, and Sweden of 850–900°C are quite common. These temperatures will become normal practice in this country in the future. If the gas turbine is to be developed here, and the conventional Cowper stoves dispensed with, heat exchangers must be designed to give a blast temperature up to 950° C.

The Chairman (Major **W. R. Brown,** Ashmore, Benson, Pease and Co.): This paper was prepared to promote general discussion, but because the use of axial-flow blowers is an innovation, this type of machine has tended to monopolize the attention of the meeting. Consequently, those reading the proceedings might infer that

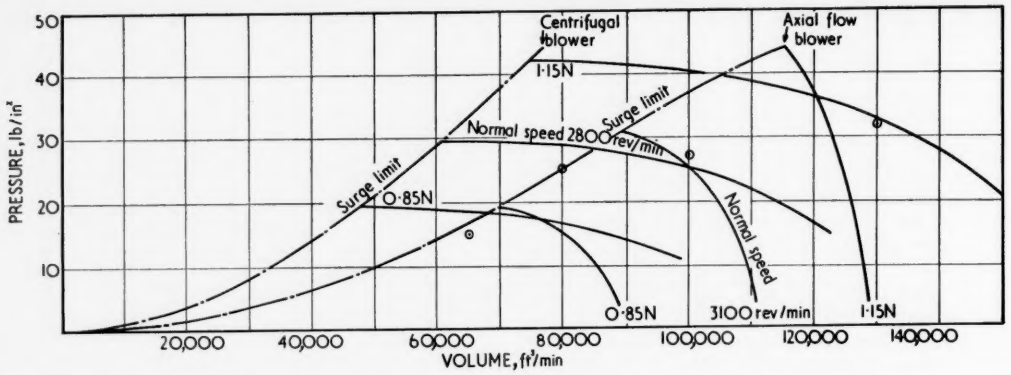


Fig. B—Typical pressure/volume characteristics for axial-flow and centrifugal blowers designed to meet a wide range of operation. Various operating duties are shown thus ○

opinion in the U.K. had swung over entirely in favour of the axial-flow blower, an inference which is not strictly correct.

I am glad that Mr. Ward has given some of the views of a blast-furnace operator, though it is a pity that more of his fraternity are not present. The blower is essentially the servant of the blast-furnace and must be judged by its suitability for the job rather than by efficiency alone. These two things may not be incompatible, but the evidence of furnace operators with experience of axial-flow blowers would have formed a valuable contribution to the discussion.

The method of ' split-wind ' blowing, to which reference was made in the paper, might, in a multiple furnace plant, answer the problem of how to obtain a wide range of blast volume without sacrificing efficiency. Two, three, or more blowers operating at peak efficiency could be used according to the demands at any particular time. Could the authors say whether the advantage of blowing at optimum revs might be outweighed by the fact that all blowers would have to deliver at the highest pressure required by an individual furnace?

Mr. **Potter:** I should like to thank the Chairman for his remarks and also The Iron and Steel Institute for its kindness in inviting us to present a paper on a subject which concerns our daily work. The compilation of the paper has been largely Mr. Duffy's work, although I have assisted him. I should like to thank the Institute on behalf of us both and on behalf of our firm for the way in which the paper has been received.

AUTHOR'S WRITTEN REPLY

Mr. **Duffy** wrote: Since the discussion took place, the ' split-wind ' blowing installation referred to in the paper has been commissioned and is working satisfactorily. The ' split-wind ' blower is at present supplying air to four furnaces, working in parallel with three of the existing blowing units, and individually blowing the fourth furnace at constant volume. With furnace blowing arranged in this way it is possible to overhaul each of the older blowing units at any time.

With regard to the Chairman's query, I would say that if the furnaces are of similar size and the blowing pressures required at individual furnaces are not vastly different, the advantage of blowing at the optimum design duty of the blower would outweigh losses due to throttling the air during furnace checks etc. If a furnace is off blast (i.e. blowing at very low pressures) then the supply from the large blower to that particular furnace is discontinued and blowing during these periods is by the smaller unit.

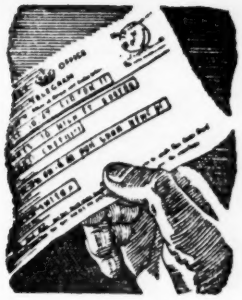
AUTUMN GENERAL MEETING, 1957

Preliminary Notice

The Autumn General Meeting of the Institute will be held in London on Tuesday, 24th September, 1957, and will be followed by the Engineers Group Meeting on " Air Pollution in the Iron and Steel Industry " at Church House, Westminster, on 25th and 26th September, 1957. The programme will be announced later. The Engineers Group Meeting on " Water Pollution in the Iron and Steel Industry " will be held at Church House on 11th and 12th December, 1957.

N E W S

Announcements and News of Science and Industry



CO-OPERATIVE TRANSLATION SERVICE

Preliminary Notice

Enquiries have shown that there is need in the iron and steel industry for improved facilities for obtaining translations of foreign technical literature, including Russian. Accordingly at the suggestion of B.I.S.R.A. the Institute has agreed to organize a Co-operative Translation Service. A number of Companies have joined in setting up a Scheme with the object of enabling a wider range of translations of technical papers to be made available and of reducing duplication in the preparation of translations. It is intended to collaborate closely with other organizations.

A central " pool " will be formed of translations prepared by each Company, and this will be supplemented by translations obtained from other sources. Translations will be sold to Members of the Institute and of B.I.S.R.A. at prices fixed in accordance with an agreed scale.

Lists of translations newly made and in course of preparation will be circulated frequently and published at regular intervals by B.I.S.R.A., B.I.S.F., and the Institute. In addition an Index is being compiled of those translations made since 1950 which are still available.

Further information will be published later.

NEWS OF MEMBERS

Mr. **D. Bruce Gardner** has been appointed a Director of Brymbo Steel Works Ltd.

Dr. **R. Genders,** M.B.E., has relinquished his position as Director of Research to the Coil Spring Federation Research Association, but he is maintaining his association with the organization in a consultative capacity.

Mr. **W. F. Gilbertson** has been appointed Executive Assistant to the Managing Director of Richard Thomas and Baldwins Ltd.

Mr. **J. E. Harris** has been awarded the degree of Ph.D. in industrial metallurgy by the University of Birmingham.

Mr. **D. C. F. Lunn** has resigned his position with the de Havilland Aircraft Co., Ltd., to become Deputy Chief Metallurgist to Atomic Power Constructions Ltd.

Mr. **Alastair McLeod** has been appointed an Honorary Vice-President of the Institute of Sheet Metal Engineering on his resignation as Honorary Secretary.

Mr. **J. F. Mills** has been appointed Manager of the new titanium plant at the Waunarlwydd Works of I.C.I. Metals Division, near Swansea.

Mr. **Esmond Morse,** M.B.E., has resigned from the Chairmanship and the Board of Directors of Brymbo Steel Works Ltd.

Dr. **B. R. Nijhawan** has been appointed Director of the National Metallurgical Laboratory, Council of Scientific and Industrial Research, Jamshedpur, India. He has also been elected recently a Fellow of the National Institute of Sciences of India.

Mr. **R. F. Perkins** has left B.I.S.R.A. to join Gillette Industries Ltd., Isleworth.

Mr. **R. Prasad** is now Associate Professor and Head of the Department of Metallurgical Engineering at the Bihar Institute of Technology, Sindri Institute, Bihar, India.

Mr. **C. T. Thomas** has been appointed General Manager of the Ebbw Vale Section of Richard Thomas and Baldwins Ltd.

Mr. **H. W. A. Waring,** C.M.G., has been appointed a Director of John Lysaght's Scunthorpe Works Ltd.

Mr. **C. R. Wheeler,** C.B.E., has been appointed a Director of John Lysaght's Scunthorpe Works Ltd. and of Brymbo Steel Works Ltd.

Mr. **L. R. Wilson** has left Quasi-Arc Ltd. to become Blade Division Metallurgist at John Garrington and Sons Ltd., Bromsgrove.

Mr. **G. A. Young** has retired from executive management and has ceased to be Assistant Managing Director of Richard Thomas and Baldwins Ltd. He remains a member of the Board.

Obituary

Mr. **William Lavender James,** who was elected a Member of the Institute in 1935, and had served as a Member of Council since 1954, died on 2nd May, 1957.

Mr. James, who was born at Stockton-on-Tees, joined the Cargo Fleet Iron Co., Ltd., in 1912. He stayed there, with a break for military service, until 1926, when he became Bar Mill Manager of the United Strip and Bar Mills, Sheffield. From 1929 to 1933 he was Superintendent of Rolling Mills, Roll Turning and Design with

Steel, Peech and Tozer Ltd. In 1933 he transferred to the Workington Iron and Steel Company as General Works Manager, and became a Director in 1938. He was in charge of production at the Shotton Works of John Summers and Sons Ltd. from 1943 to 1948, and in April, 1948, he became Director and General Manager at the Normanby Park Works of John Lysaght's Scunthorpe Works Ltd. He was responsible for the £11½ million expansion scheme at that works. Ill health compelled him to retire from the industry in 1956.

Mr. **Leonard John Webb Felgate** (*elected* 1947), of London, on 27th April, 1957.

Mr. **Ronald Whale** (*elected* 1951), of London, on 12th April, 1957, as the result of a car accident.

Mr. **Henry Edward Wright** (*elected* 1918), of Sheffield, on 13th January, 1957.

AFFILIATED LOCAL SOCIETIES

Ebbw Vale Metallurgical Society

At the Annual Meeting of the Ebbw Vale Metallurgical Society held on 30th April, 1957, the following officers and committee were elected for the session 1957–1958:

President
J. T. Mills
Vice-President
P. Edwards
Honorary Treasurer
W. E. Williams
Honorary Joint Secretaries
F. W. Lewis
W. B. Williams, L.I.M.
Members of Committee
J. J. Beese, R. M. Bethel, W. H. R. Bird, M.A., B.SC., W. Cook, W. Edny, A. W. Ellis, A.M.I.E.E., W. Goatman, G. Giddings, L. G. Hobbs, T. Jones, A. J. Meo, D. L. Mills, R. C. Powell, B.SC., F. E. Probyn, J. F. Smith, J. B. Thickins, B.SC.

Liverpool Metallurgical Society

At the Ninth Annual General Meeting of the Liverpool Metallurgical Society, held on 11th April, 1957, the following officers and committee were elected for the session 1957–1958:

President
J. S. W. Graham, M.ENG., A.M.I.E.E.
Senior Vice-President
C. Bodsworth, M.MET., A.I.M.
Vice-President
B. Ryan
Retiring President
W. Rose, J.P.
Honorary Secretary
J. F. Giblin, B.ENG., A.I.M.
Honorary Treasurer
B. Todd, M.ENG.
Members of Committee
W. J. Bannister, B.SC., G. T. Callis, B.SC.(TECH.), F.I.M.; J. Clark; R. Cobill; A. E. Griffin, M.INST.W.; W. A. Jenks.
Honorary Vice-Presidents
R. S. Brown, M.B.E., A.M.C.T., F.I.M.; H. Edwards, F.R.I.C., F.I.M.; V. L. FARTHING, M.I.MECH.E., M.I.MAR.E.; S. J. Kennett, B.SC., A.R.S.M., PH.D., F.I.M.

EDUCATION

College of Aeronautics

In view of the increasing importance of materials and metallurgy in the aircraft industry and aeronautical research, the Governing Body of the College of Aeronautics, Cranfield, has created a Professorship in Materials and Metallurgy. The first Professor is Dr. A. J. Kennedy, A.M.I.E.E., F.INST.P., formerly Head of the Metal Physics Section of the British Iron and Steel Research Association. Professor Kennedy, who has become Head of the Section already dealing with this subject, will have special responsibilities in developing its research activities and in encouraging and supervising more advanced studies, particularly in the field of physical metallurgy.

Summer Course at M.I.T.

The Metals Processing Division of the Department of Mechanical Engineering at the Massachusetts Institute of Technology is holding a special summer course in "Wear Theory in Metal Cutting and Bearing Design" from 17th to 28th June. Full details of this and other summer courses may be obtained from the Institute.

Conference for Junior Employees

"Responsibility" was the theme of the third United Steel's weekend course for apprentices and junior operatives held at Downing College, Cambridge, from 12th to 15th April. Over 100 junior employees from all branches attended the course, during which they heard talks given by leading industrial and educational authorities and took part in discussion groups. Among the speakers were Lt.-Comdr. G. W. Wells, general manager of Appleby-Frodingham Steel Company, Mr. Denis McMahon, director of Edinburgh University's Applied Psychology Unit, and Mr. Eric Hiscock.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

'Open Days' at Sketty Hall

As announced in the April issue, Open Days are being held at B.I.S.R.A.'s Swansea laboratories on Wednesday, 19th, and Friday, 21st June.

One of the most important of the displays and demonstrations to be mounted will be the P.V.C.-steel laminate project. Developments have reached an advanced stage, and the recently installed pilot line is already producing limited quantities of continuously laminated strip for subsequent user trials. The laminate combines the decorative and durable finish of plastic with the strength of steel, and, being capable of severe deformation (it can be bent, crimped, sheared, or even deep drawn), it has a wide range of manufacturing applications. The material can be produced in a variety of colours, and with either a plain or an embossed surface.

A similar laminate has been produced in the U.S.A., where the product is finding a ready market. American efforts, however, have been mainly directed towards the production of separate laminated sheets, while B.I.S.R.A.'s work has been directed to the development of the continuous strip process and general improvement in the laminating process, using materials available in this country.

Formal invitations to the Open Days are being issued to B.I.S.R.A. member firms. A general invitation is, however, extended to all industrialists and others interested in coated steel and its many applications, and the Information Officer of B.I.S.R.A. at 11 Park Lane, London, W.1. will be glad to hear from those wishing to attend.

NEWS OF SCIENCE AND INDUSTRY

Centenary of *La Revue Universelle des Mines*

The centenary of *La Revue Universelle des Mines* was celebrated by a special meeting in Liège on 6th–8th May,

1957. The meeting was arranged by the Association des Ingénieurs sortis de l'Ecole de Liège, which was founded in 1847 and whose official publication is the *Revue*.

The meeting was devoted to the subject of " Scientific Research and Industry." After the opening ceremony, the first two days were devoted to different aspects of this subject in Belgium, and on the final day the meeting was addressed by representatives of other European countries. Mr. A. C. Coparisow, H.M. Scientific Attaché at the British Embassy in Paris, spoke on the relationship between research and industry in the United Kingdom.

" Steel Rhythm "

A colour film lasting 35 minutes has recently been produced by the Steel, Peech and Tozer branch of the United Steel Companies Ltd. It is designed to give an impression of the activities of the works, with emphasis on quality control. After a general picture of the extent of the works, its supplies, and its staff, the film deals in detail with in turn, the melting shop, the rolling mills, and the forging presses. This admirably produced film is a fine tribute to those employed at the Steel, Peech and Tozer works, and should also be in demand for teaching purposes, for it provides a very full and accurate picture of steelmaking and transforming processes.

B.I.S.F. Annual Report for 1956

The Annual Report of the British Iron and Steel Federation for 1956 gives the latest details of the industry's plans for further expansion. During 1957 steelmaking capacity should reach 24 million tons, and by 1962 it should exceed 28 million tons on the plans already put forward. This programme includes fourteen new blast-furnaces, eight new or extended melting shops, and six 4-high plate mills. An appendix gives details of the industry's fleet of specially built ore carriers, which is expected to comprise 72 vessels by 1962, with an annual carrying capacity of over 10 million tons.

Steel supplies during the year to the home market were one million ingot tons higher than in 1955, three-quarters of this being used to build up stocks. Production for 1957 is expected to be over 22 million tons, compared with 20·7 million tons in 1956; this should lead to substantial reductions in steel imports.

Meeting on Powder Metallurgy

A meeting of the Ausschuss für Pulvermetallurgie, which is jointly sponsored by the Verein deutscher Eisenhüttenleute, the Verein deutscher Ingenieure, and the Deutsche Gesellschaft für Metallkunde, will be held in Düsseldorf on 27th and 28th June. Papers will be presented on the grinding and pressing of metal powders, the properties of powders, physical aspects of the sintering process, toughness and hardness testing of carbides, etc. Full details may be obtained from the Ausschuss, Breite Strasse 27, Düsseldorf, Germany.

New Open-hearth for John Summers

A new 240-ton open-hearth furnace has recently been commissioned at the Hawarden Bridge Steelworks of John Summers and Sons Ltd.

Belgrade International Fair

An International Technical Fair is to be held in Belgrade from 23rd August to 2nd September. Amongst the industries represented will be iron and steelmaking and electrical and chemical engineering.

Continuous Casting Co., Ltd.

The Continuous Casting Co., Ltd., of Weybridge, is now associated with Davy and United Engineering Co., Ltd., and Newton Chambers and Co., Ltd. Sir Peter Roberts, BT., M.P., and Mr. K. E. Walker, of Newton Chambers, and Mr. M. A. Fiennes and Mr. M. F. Dowding, of Davy-United, have joined the Board.

Davy British Oxygen Limited

The increased use of oxygen for metallurgical duties brought about by the low cost resulting from production on tonnage scales has led to the development of new steelmaking processes. These new processes bring together the metallurgical techniques involved in the development and design of steelmaking plant with the application of tonnage oxygen.

A new joint company—Davy British Oxygen Limited —has been formed which will make available to the steel industry ' oxy-steel ' processes utilizing the steel-plant manufacturing resources of Davy and United Engineering Co., Ltd., Sheffield, and the metallurgical techniques and tonnage oxygen plant manufacturing facilities of British Oxygen Engineering Ltd. and British Oxygen Linde Ltd.

The capital of the new company will be held equally by Davy and United Engineering Co., Ltd., and by The British Oxygen Co., Ltd., and the directors will be Mr. M. A. Fiennes and Mr. M. F. Dowding of Davy and United Engineering Co., Ltd., and Dr. P. H. Sykes and Mr. F. J. Clark of The British Oxygen Co., Ltd. The registered offices will be Bridgewater House, Cleveland Row, St. James's, London, S.W.1.

International Mineral Dressing Congress

As mentioned in the May issue, an International Mineral Dressing Congress is being held in Stockholm from 18th to 21st September, 1957.

Altogether 33 papers from 11 different countries have been received. Preprints of these are being sent out shortly to those attending the congress; they will be reprinted in due course in the Transactions of the Congress. They are being presented at seven ordinary technical sessions under the following headings: I. Comminution; II, Classification and Gravity Separation; III. Magnetic Concentration, Roasting, and Sintering; IV. Flotation Theory; V. Flotation of Sulphide Ores; VI. Flotation of Non-sulphide Ores; VII. Mineral Processing by Chemical Methods.

Written contributions to the discussion are invited for subsequent publication in the Transactions. Those interested should write to the General Secretary of the Congress, Nackströmsgatan 1III, Stockholm C, Sweden.

Gillett Memorial Lecture

The 6th Gillett Memorial Lecture will be presented at the 60th Annual Meeting of the American Society for Testing Materials at Atlantic City, N.J., U.S.A., on 18th June. The lecturer will be Mr. Alvin J. Herzig, President of the Climax Molybdenum Company, who has chosen as his subject " A Perspective of Mo-Base Alloys."

Fire Drill Leaflet

A new leaflet entitled " Fire Drills in Factories " has recently been circulated to over 65,000 factory occupiers by H.M. Chief Inspector of Factories. The leaflet marks a further stage in the Ministry of Labour's drive to improve factory fire precautions, which began last year. Steps taken so far include the issue of an advisory leaflet on fire alarms, a nation-wide survey of factories where fire alarms are required, and a closer examination of means of escape in case of fire. The new leaflet stresses in particular the need for a plan to be worked out that can be implemented should fire occur.

Electric Steel Makers' Guild

A new technical society to be known as the "Electric Steel Makers' Guild" has recently been formed and began its first year on 1st May.

The purpose of the Guild is to promote progress in the manufacture of steel for commercial purposes in electric melting furnaces, and to encourage free discussion and exchange of information of mutual interest to members.

Membership is limited to executives who are regularly employed directly in the manufacture of electric furnace steel for commercial use; meetings, which will be held two or three times each year, will be quite informal. No records of technical discussions will be made or published and members will be encouraged to discuss freely their own and others' problems.

A similar society which has been in existence for the past 25 years in the U.S.A. has been highly successful and enjoys great popularity in the steel industry.

The officers appointed for the first year are:

President: Mr. R. Lamb (Hadfields Ltd.)

Vice President: Mr. F. T. Bagnall (S. Fox and Co., Ltd.)

Secretary: Mr. A. Mettam, English Steel Corporation Ltd., Grimesthorpe Works, Sheffield 9.

New Licence Arrangements

The Electric Furnace Co., Ltd., Netherby, Queens Road, Weybridge, Surrey, have obtained an exclusive licence from the Lectromelt Furnace Company of Pittsburgh, U.S.A. for the U.K., Australia, New Zealand, etc. (with non-exclusive rights in other countries) for the sale of Efco-Lectromelt arc furnaces. Efco Ltd. have been building electric arc furnaces since 1910, whilst the Lectromelt Company pioneered the swing-roof arc furnace in sizes from $\frac{1}{4}$ ton to 200 tons.

Transfer Plant Contract

The United Steel Structural Co., Ltd., have recently placed a contract with Chamberlain Industries Ltd., of Leyton, for the manufacture, supply, and installation of a transfer plant for processing rolled-steel sections semi-automatically, to be installed in the company's works at Scunthorpe.

Ceramic Cutting Tools

English Steel Tool Corporation Ltd., Openshaw, Manchester, have recently made an agreement with Lodge Plugs Ltd., of Rugby, for the distribution of 'Sintox' ceramic cutting tool material in the U.K. A period of intensive research preceded this development, and English Steel Tool Corporation Ltd. now has a team of trained technicians to assist in the application of this new material.

Changes of Address

The Technical Sales and Service Department of Acheson Colloids Ltd., is now at 70 Hill Street, Richmond, Surrey (telephone RIChmond 2066 and 2634).

The telephone number of the Scottish Office of Wild-Barfield Electric Furnaces Ltd., 147, Bath Street, Glasgow C.2, is now City 4878.

Industrial Publications

"*Combating Corrosion—with Economy*" is the title of Technical Bulletin No. 2 issued by T. and R. Williamson Ltd. of Ripon; it deals with metal primers and their relationship to ferrous and non-ferrous metals.

Research Bibliography No. 53, obtainable free from the City Librarian, Central Library, Sheffield 1, is devoted to the strength of single metal crystals.

'Power Vane' grinders are described in the new 24-page catalogue issued by the Consolidated Pneumatic Tool Co., Ltd.

The Lafarge Aluminous Cement Co., Ltd., have issued a 16-page brochure on 'Secar 250,' a new calcium aluminate cement capable of withstanding temperatures up to 1800° C.

The 'Multistroke' hand-lift trucks, of 3000 and 5000 lb capacity, are described in specification bulletin no. B.508A of the Yale and Towne Manufacturing Co., Wednesfield.

A data sheet on level control for solids and non-conductive liquids has been published by Elcontrol Ltd.

Radio Heaters Ltd. give details in a recent brochure of a new 1-kW induction heater.

DIARY

5th–10th June—World Power Conference—Sectional Meeting—Belgrade.

17th–29th June—British Commonwealth Welding Conference—London and Saltburn-by-the-Sea.

19th and 20th June—British Iron and Steel Research Association—11th Junior Steelmaking Conference—Ashorne Hill.

19th and 21st June—British Iron and Steel Research Association—Open Days—Sketty Hall, Swansea.

19th–22nd June—Institute of British Foundrymen—Annual Conference—Harrogate.

23rd–28th June—American Society for Testing Materials—Annual Meeting—Atlantic City, N.J., U.S.A.

23rd June–3rd July—German Welding Society (D.V.S.)—Welding and Cutting Exhibition—Essen.

24th–28th June—Society of Analytical Chemistry (Scottish Section)—Congress on Modern Analytical Chemistry in Industry—St. Andrews.

24th–28th June—11th International Congress on the Organization of Science—Paris.

27th–28th June—Ausschuss für Pulvermetallurgie—Meeting on Powder Metallurgy—Düsseldorf.

30th June–3rd July—Institution of Production Engineers—Conference on Automatic Production—Harrogate.

1st–6th July—International Institute of Welding—Annual Assembly—Essen.

2nd July—Fulmer Research Institute—Open Day—Stoke Poges.

3rd–6th July—Commission on the Physics of Solids (IUPAP) and National Science Foundation—Conference on Current Problems in Crystal Physics—Cambridge, Mass., U.S.A.

9th–20th July—Cambridge University—Summer School on the Use of Electrons in the Examination of Metals—Cambridge.

TRANSLATION SERVICE

(The previous announcement was made in the May, 1957, issue of the Journal, p. 116).

Translations Available

No. 526 (Russian). Yu. A. Geller: "Determination of the Mechanical Properties of Tool Steels." (*Zavodskaya Laboratoriya*, 1955, vol. 21, No. 5, pp. 594–601).

No. 527 (German). S. Kienow, K.-P. Breitel and K. Heinemann: "The Wear of Runner-Bricks, Depending on the Refractory and the Steel Composition." (*Stahl und Eisen*, 1956, vol. 76, Nov. 1, pp. 1416–1424; discussion, pp. 1424–1426).

No. 528 (German). K. G. Speith, H. v. Ende and H. J. Seelisch: "Non-Metallic Deposits on the Git and Wear of Runner-Bricks with Killed Open-Hearth Steels." (*Stahl und Eisen*, 1956, vol. 76, Nov. 1, pp. 1426–1438; discussion, pp. 1439–1441.)

Translations in Course of Preparation

(German). W. Lueg and H. G. Müller: The Load on a Three-High Finishing Stand and on Its Drive in Hot-Rolling Sheet Bars and Billets." (*Stahl und Eisen*, 1956, vol. 76, Nov. 1, pp. 1457–1463).

ABSTRACTS OF CURRENT LITERATURE AND BOOK NOTICES

Iron and Steel Manufacture and Related Subjects

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MINERAL RESOURCES

The Economic Geology of the Stirling and Clackmannan Coalfield, Scotland, Area North of the River Forth. E. H. Francis, M. A. Calver, and R. B. Wilson. (*Dep. Sci. Ind. Res. Coalfield Papers of the Geological Survey of Great Britain*, 1956, No. 1, pp. 53).

The Magnesite Deposits of Breitenau bei Mixnitz, Steiermark. W. Zschucke. (*Berg. Hüttenmann. Monatsh.*, 1956, **101**, Jan., 1–12). A full account of large and small scale features.

ORES—MINING AND TREATMENT

Iron Mines in Western France. (*Echo Mines*, 1956, Oct., 581–584). A survey with map.

Fragmentation of Rock Overburden. T. W. Edmond. (*Mine Quarry Eng.*, 1957, **23**, Jan., 18–23; Feb., 52–57). Drilling and blasting practice at the Corby ironstone deposits, including the use of a horizontal drilling method, are described in an illustrated article.

The Reserve Mining Co. Project: Time Table of Progress from Discovery Pit to Production. (*Eng. Min. J.*, 1956, **157**, Dec., 76–79). A chronological account is given of events, including the discovery of taconite at Babbitt in 1871; its exploitation between 1922 and 1924, when the beneficiated ore failed to compete with direct-shipping ore; the establishment of Reserve Mining Co. in 1939; experiments on pelletized ore; the erection of a beneficiation plant at Silver Bay, completed in 1955; and exploitation of the ore and production of pellets during 1956. A complete flowsheet and descriptions are given for the items of present-day equipment at Babbitt and Silver Bay. **The Orebody and How it is Mined.** (*Eng. Min. J.*, 1956, **157**, Dec., 80–85). An account is given of the geological features of the orebody and of the winning and crushing of the ore. The orebody contains $1{\cdot}5 \times 10^9$ tons of magnetic taconite, containing 25–30% Fe. The hard ore (600 Brinell) is drilled by jet-piercing techniques. At Babbitt the ore is crushed to 9 in. in a 60-in. cone crusher, then to 4 in. in 30-in. crushers before loading to trains. **Silver Bay and the E. W. Davis Works.** (*Eng. Min. J.*, 1956, **157**, Dec., 86–87). A plan of the works at Silver Bay is given, with brief details of the fine-crushing plant, concentrator, pelletizing plant, power plant, and harbour. The plant now produces $3{\cdot}75 \times 10^6$ tons of pellets per year, and its ultimate production may reach 10^7 tons. **The Concentrator at Silver Bay, Stockpiling, Materials-handling Equipment and Loading Units.** (*Eng. Min. J.*, 1956, **157**, Dec., 88–101). A brief account is given of the plant. The primary shorthead cone crushers reduce the –4 in. feed to $-1\frac{1}{4}$ in., and the secondaries reduce this to $-\frac{3}{4}$ in. This is rod-milled to –10 mesh and ball-milled to 80% –325 mesh. The product is concentrated by rough magnetic separation, cyclone classification, hydro-separation and finishing magnetic separation, to give a product having 62·5% Fe. The pelletizing process consists of balling with added bentonite binder, coating with fine anthracite, heating on 28-windbox moving-stand machines burning oil, and quenching.—K. E. J.

Evolution of Iron Ore Beneficiation Processes. S. E. Erickson. (*Blast Furn. Steel Plant*, 1956, **44**, Oct., 1159–1167; Nov., 1291–1295). Iron ore preparation and beneficiation in America is discussed with particular reference to the Lake Superior iron ores. Plants for crushing and screening and for concentration of the ore by heavy-medium separation are described.—B. G. B.

Theoretical Studies on Magnetic Separation. II. Effects of Demagnetizing Field on the Magnetization of Irregular Form Mineral Particles. S. Yashima and T. Ohyama. (*Tohoku Univ. Techn. Repts.*, 1956, **20**, (2), 197–211).

Problems of Metallurgy. Academy of Sciences of the U.S.S.R., Moscow, 1953. **On the Oxidation of Metal Sulphides with Oxygen.** G. S. Frents and O. M. Chizhikov. (107–116). [In Russian]. **Value of the Coefficient k in the Formula for Determining the Weight of Representative Samples of Iron Ores.** N. N. Chinkin. (153–156). The value of the proportionality coefficient k in the equation relating the weight of the representative ore sample with the diameter of the largest lumps is discussed for various conditions. Experimental results are reported. **Methods of Beneficiating Krivoi Rog Iron Ores.** G. I. Yudenich. (157–178). After an outline of the history and geology of the Krivoi Rog deposits, methods of beneficiating martite, magnetite and martite–magnetite ores are described. **Fundamentals of Sintering Ores.** A. M. Parfenov. (179–198). In this discussion of the theory of sintering the movement of water in the bed, the ignition and combustion of the fuel and the physical and chemical changes occurring at various stages of the sintering of iron ores are considered.—S. K.

Iron Agglomerates from the Marquette Range. F. W. Starratt. (*J. Met.*, 1956, **8**, Nov., 1546–1548). The Cleveland-Cliffs Iron Co. is now processing the siliceous jasper ores of the Marquette Range into a concentrate suitable for blast

furnace charging. A summary of the operations involved is given.—G. F.

A Study of Sinters of Orconera Carbonate Ores. J. A. Boned Sopena and E. Charro Sanchez. (*Inst. Hierro Acero*, 1956, **9**, July-Sept., 991–1013). [In Spanish]. A study is reported of the relationships of the production rates, properties, and desulphurization of sinters of Orconera ores (47·1% FeO, 7·53% Fe_2O_3, 31·37% CO_2, and 0·327% S) as a function of the proportion of coke used in the charge. Between 1·78 and 7·57% coke additions were made and the optimum was found to be 3·52% coke giving 86% desulphurization of the charge. Further improvement was obtained by using a double sinter layer, each of equal thickness but with 3·52% coke in the upper layer and 2·68% in the lower. Anomalous behaviour was observed over the range 4–6% coke due to the temperature distribution in the charge and variations in the thickness of the calcination zone. The constitution and microstructure of these sinters is also reported, and in the sinter made with 7·57% coke a new vermicular type of texture was observed. This is thought to result from magnetite oxidized below 498° C which neither changes its structure nor becomes Fe_2O_3, but later decomposes to a mixture of Fe_3O_4 and $\alpha.Fe_2O_3$. (20 references).—P. S.

Study on the Manufacture of Excellent Sinter by Magnetising Roasting of Limonite. I. Fundamental Study. S. Sato. (*Tetsu to Hagane*, 1956, **42**, Mar., 213–215). [In Japanese]. The bonding, chemical changes, and elimination of sulphur and arsenic during sintering are discussed. Figures for crushing strength, yield, and coke usage demonstrate the advantages of a magnetic roast when sintering a burden containing 45% of limonite. **II. Pilot Plant Test.** T. Ikeno. (215–217). A flowsheet is given for a plant to roast 120 tons per day. X-ray diffraction patterns are given for various sintered ores. Magnetic roasting has the effect of reducing coke requirements by 1% to make sinter of the same reducibility in hydrogen, and simultaneously increases the strength and yield.—K. E. J.

Sintering Test of Iron Ores in a Small Sintering Pan. K. Yazuka. (*Tetsu to Hagane*, 1956, **42**, Mar., 212–213). [In Japanese]. Details are given of sintering variables and sinter properties for binary mixtures of Kamaishi, Miyakawa, and Dungun ores in different ratios.—K. E. J.

Sintering Test of Iron Ores by Small Greenawalt Type Sintering Structure. II. Observation of Microscopic Structure of Iron Sinters. N. Nishida. (*Tetsu to Hagane*, 1956, **42**, Mar., 297–299). [In Japanese]. Sinters made from Zungun ore (4% and 8% coke), and from iron sand and Kamaishi fines (3% and 7% coke in each case), are examined from their micro-structures.—K. E. J.

Sintering Test of Fine Pyrites Cinder. K. Mikayawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 211–212). [In Japanese]. Details of sintering times, yields, wind velocities, and sinter properties are given for burdens containing 50% pyrites cinders of various sizes. The deleterious effects of − 100 mesh materials are shown.—K. E. J.

Behind the Swing to Sintered Ore. G. J. McManus. (*Iron Age*, 1956, **178**, Oct. 18, 83–85). The large expansion in sintering capacity of the U.S. steel industry in the immediate future, is reported. Size and location are given for the 18 sinter machines under construction, which will have an output of 25 million tons.—D. L. C. P.

Various Aspects Relating to the Reduction of Ores in the Renn Process. M. Mendez de Vigo and J. Lopez Varela. (*Inst. Hierro Acero*, 1956, **9**, July-Sept., 971–990). [In Spanish]. The principles of the Renn process for the production of nodules are given and followed by a discussion of the factors which affect the process. These include a study of the reactions in the fusion zone and details of the thermal balance but concern mainly the slag formation and nature. The slag is required to be acidic in character, pasty in the 1200–1300° C range and to have the necessary fluidity in the nodule-forming zone. The principal slag-forming constituents are discussed and it is shown that they must be kept within the limits 60–80% SiO_2, 10–20% Al_2O_3, 10–20% CaO with a CaO/SiO_2 ratio between 0·125 to 0·250, for satisfactory operation. Examples are given of the results obtained with a variety of charges.

On the Magnetizing Roasting of Ni–Cr Iron Ore by Fluidized Bed. T. Mitsuhashi, M. Ueno, and M. Tanaka. (*J. Mech. Lab.*, 1956, **2**, 36–37). High iron and nickel recoveries are reported from low-grade ores.

Report on the Manufacture of Sponge Iron in Japanese Special Native Furnaces. (Kaku-Gama and Nobori-Gama) during the War. H. Sawamura. (*Suiyokwai-Shi, Trans. Min. Met. Alumni Assoc.*, 1956, **13**, May, 79–82). Porcelain kilns were used.

Methane Reduces Iron Ore in Fluid Bed. (*Chem. Eng.*, 1957, **64**, Jan., 130, 132, 134). An account of a pilot plant giving iron powder with 5–30% FeO. It may be economic in small units, uses finely powdered ores directly, and is suitable for natural gas areas.

Possibilities of the Application of Hydrogen to the Reduction of Pulverised Native Ores. J. Wscieklica. (*Bol. Assoc. Brasil. Met.*, 1955, **11**, Oct., 389–409). [In Portuguese]. The advantages of hydrogen reduction are discussed and a comparison is made between hydrogen and carbon monoxide reduction. A description of the apparatus used for laboratory-scale tests is given; it consists essentially of a supply of dry hydrogen, a furnace made of dead-mild steel and apparatus for measuring the outgoing gases. Samples of 150 g were used in the furnace at 550° C and a hydrogen flow of 8·5 l. per min; the ore contained an average of 98·95% Fe_2O_3. Reduction curves are given for samples of various grain sizes, the best results being obtained with a grain size of − 20 to + 40 mesh giving a reduction of over 95% in about 2 h. It is intended to build (*a*) a furnace which will give more intimate gas–ore contact, (*b*) a furnace to give 10 kg of sponge iron per h, and (*c*) a pilot plant with a capacity of 16–24 t per day if the earlier results confirm expectations. (23 references).—P. S.

FUEL—PREPARATION, PROPERTIES, AND USES

Chemistry of Coal and its Relation to Coal Carbonization. I. G. C. Dryden. (*Inst. Fuel, Advance Copy*, 1957, Jan., pp. 22). Gas, tar, and tar-acid yields are correlated with composition.

Cleaning by Flotation of Fines of the Categories 0/1-Slimes and Dust. Choice of Reagent. Industrial Results. J. Baudry. (*Publ. Assoc. Ing. Faculté Polytechn. Mons*, 1956, (4), 1–9). Flotation tests on coals are described using creosote and mixtures with Tensatil. Many tables and curves are given.

Rapid Method of Control and Prediction of the Performance of Coal Washeries. P. Moiset. (*Publ. Assoc. Ing. Faculté Polytechn. Mons*, 1956, (4), 17–25). U–R diagrams are given and their uses explained.

Avenue Carbonization and Chemical Plant—Wingerworth, Chesterfield. (*Iron Coal Trades Rev.*, 1956, **173**, Nov. 9, 1127–1138). The Avenue plant, the National Coal Board's largest and most up-to-date carbonizing plant, was recently officially opened. Details are given of the layout and design of the coke-oven plant; coal handling, blending, and crushing systems; oven charging and coke pushing; coke discharging, quenching, handling, and screening; gas collecting and purification plant; acid plant and effluent treatment; steam-raising plant; and services.—G. F.

Additional Note on the Lorraine Coke Ovens. (*Echo Mines*, 1956, Oct., 571–573). The review in the July issue is completed by descriptions of the C.G.C.F. and Carling installations.

On the Manufacture of Shaped Metallurgical Coke from Inferior Coals. II. S. Ida. (*Tetsu to Hagane*, 1956, **42**, Mar., 226–228). [In Japanese]. Results are given of briquetting tests on various caking, weakly-caking, and non-caking coals and blends.—K. E. J.

Metallurgical Coke: A Formula for its Price. (*Inst. Nac. Carbon Bol. Inf.*, 1955, **4**, Nov., 312–318). [In Spanish]. A formula giving the price the industry is able to pay for blast furnace coke is established. This price, in pesetas per wagon-ton, is given by $P = 590 + 8\ (S-60) + 15\ (16-c)$ where S is the 'solidity' and c is the ash%, and applies to cokes with a solidity of greater than 60 and ash contents of less than 16%. The formula is based on the fixed price of 530 pesetas per ton for coke with a solidity of less than 60 and an ash content of 20%. The solidity index is obtained from $S = M-1·5\ m$, where M is the Micum drum test index and m is the abrasion index: these are the fractions of greater than 40 mm and less than 10 mm respectively, produced in the drum test.—P. S.

Combustion Characteristics of Coke-oven Gas Flames. J. Yamauchi. (*Tetsu to Hagane*, 1956, **42**, Mar., 272–274). [In Japanese].—K. E. J.

Gases Cleaned by the Use of Scrubbers. B. Basse. (*Blast*

Furn. Steel Plant, 1956, **44**, Nov., 1307–1310, 1312). The use of venturi gas scrubbers for cleaning blast-furnace gas, O.H. and converter fumes is discussed.—B. G. B.

AIR POLLUTION AND SMOKE

Measurement of the Optical Density of Smoke in a Chimney. A. Littlewood. (*J. Sci. Instruments*, 1956, **33**, Dec., 495–499).

Two Modern Methods of Combating Air Pollution in the Foundry, as in the Iron and Steel Industry. J. Kistler. (*Giesserei*, 1956, **43**, June 21, 333–340). Industrial dust is first discussed in general terms. Health hazards are then considered for various types of dust. The sources of dust in foundry and iron-works and their yields are cited. Various methods of solving the dust problem are stated and described in detail. These include the Venturi separator, the use of filters, the Elex-Schneible wet separator, and the use of exhausting funnels for both smoke and dust.—R. J. W.

A Short Monograph on Dust Technology. Properties and Behaviour of Iron Oxide Aerosols. (*Arch. Eisenhüttenwesen*, 1956, **27**, Nov., 673–679). Properties of hematite, martite, maghemite, and magnetite, "brown smoke," formation of iron oxide smoke, shape of individual particles and agglomerates, precipitation of iron oxide smoke by water, and wettability are discussed.—L. J. L.

REFRACTORY MATERIALS

Treating Silica Brick to Eliminate Dust. C. E. Cline and R. A. Bloom. (*Blast Furn. Steel Plant*, 1956, **44**, Nov., 1302–1304). Steps taken to reduce the dust hazard during handling of silica bricks in electric arc furnace roof construction are described. The use of special shapes and enclosed vented saws reduced dust when cutting was necessary. The most satisfactory method of reducing dust during handling was dipping into a solution of ammonium lignosulfonates.

Studies on Unburned Refractories, III. S. Nagai, Z. Ota, F. Tanemura, and M. Tsukino. (*Annual Report, Engineering Research Institute. Faculty of Engineering, University of Tokyo*, 1956, **15**, Sept., 24–27). Studies on the SiO_2–Al_2O_3 system are continued and comparisons with U.S. high-alumina plastic refractories are made.

A Study of the Tridymite Transformation of Four Spanish Quartzites and its Application to the Manufacture of Silica Bricks. V. Aleixandre Ferrandis and C. Sanchez Conde. (*Inst. Hierro Acero*, 1956, **9**, July, 763–794, Special Number), and with J. Garcia Vicente (July-Sept., 941–952). [In Spanish]. In the first section, the results of an investigation of the grain size and chemical and physical nature of these quartzites in the raw state and after calcining, are described. They were then pulverized, proportioned, mixed with an agglomerant and a mineralizer (either lime and sodium oxide, or lime and a frit of sodium oxide, ferric oxide and silica), moulded and fired at either 1200°, 1350°, or 1420° C. From a study of the important physical properties of these fired samples, it is concluded that (*a*) if the mineralizer contains oxide then tridymite transformation is appreciable even at 1350° C, (*b*) there is no correlation between the true density and the % tridymite formed, (*c*) dilatation measurements give a qualitative measure of the allotropic transformations of quartz, and (*d*) those test pieces which contained iron oxide and lime showed better agglomeration and abrasion resistance after firing. In the second part, the authors investigate the degree of tridymite transformation by petrographic and X-ray methods. These results confirmed the previous observations. (41 and 5 references).—P. S.

Effect of Temperature and Additives on the Creep Properties and Recrystallization of Aluminium Oxide. R. P. Cahoon and C. J. Christensen. (*PB.* 121000, 1955, pp. 116; TIDU List 645). Additions of 5 anions and 19 cations were investigated at 875–1350° C.

The Measurement of Thermal Conductivity of Refractory Materials. F. H. Norton and W. D. Kingery. (*AEC.NYO.* 602, 1952, pp. 42; TIDU List 550). Zircon, TiO_2, and mullite were investigated 200–1400° C, and Al_2O_3, BeO and MgO up to 1800° C. The ellipsoid envelope method is discussed.

The Measurement of Thermal Conductivity of Refractory Materials. W. D. Kingery and F. H. Norton. (*AEC.NYO.* 6451, 1955, pp. 18; TIDU List 550). The systems MgO–SiO_2 and Al_2O_3–ZrO_2 and polycrystalline TiO_2 are studied. Infrared absorption data are given for fused SiO_2 and sapphire up to 1200° C. An expression for radiant heat transfer in opaque powders is given in an appendix.

Attack on Open-hearth Refractories by Iron Oxide; Effect of Contaminants. W. A. Archibald. (*Iron Coal Trades Rev.*, 1956, **173**, Dec. 14, 1443–1446). The author discusses the chemical and physical aspects of iron oxide attack on O.H. silica bricks exposed to various furnace atmospheres. The unique fine structure of silica leads to its low solubility in iron oxide liquids, and in general the normal changes in atmosphere have a considerably greater effect on solubility than variations in normal operating temperature.—G. F.

On the Spalling of Ladle Refractories. Y. Isono. (*Tetsu to Hagane*, 1956, **42**, Mar., 336–338). [In Japanese]. Several refractories are described by type and physical and refractory properties, and are then classified according to the fissures produced after service in the ladle.—K. E. J.

On the Erosion of Ladle Refractories. Y. Isono. (*Tetsu to Hagane*, 1956, **42**, Mar., 338–340). [In Japanese]. Five refractories (Roseki, fireclay, and high-alumina) are compared in respect of erosion by slag, molten steel, and molten steels of different Mn/Si ratio.—K. E. J.

The Wear of Runner Bricks in Relation to Type of Bricks Used and Composition of the Steel Produced. S. Kienow, K.-P. Breitel, and K. Heinemann. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1416–1426). Investigations on the wear of runner bricks were carried out with silica- and alumina-rich bricks unglazed and glazed with alumina and silicon carbide and rimming and killed steels of various composition. The results are presented in detail, illustrated by tables, graphs, constitutional diagrams and micrographs. Glazing the bricks with bauxite protects them completely in contact with killed steel, but only slightly in contact with rimming steel. Silicon carbide gives no protection.—T. G.

Non-metallic Deposits on the Sprue and the Wear of Runner Bricks from the Pouring of Killed Open-Hearth Steels. K. G. Speith, H. vom Ende, H.-J. Seelisch. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1426–1441). In the pouring of killed open-hearth or basic-Bessemer steels non-metallic deposits are found on the runner bricks. These deposits are residues from the deoxidation process which have not risen to the surface in the ladle. The nature of the deposits depends on the deoxidation agents added. The deposits were analysed chemically and by X-ray methods. The wear of the runner bricks was also studied. It was found that wear decreases with increasing alumina content and is highest at the joints of the bricks. However, wear of the runner bricks is closely related to the nature of the non-metallic residues in the melt. The wear of the runner bricks is relatively small and the products do not impair the purity of the steel to any noticeable extent, whereas they retain about 40% of the deoxidation residues.—T. G.

IRON AND STEEL, GENERAL

The Russian Iron and Steel Industry. Sir R. Shone, W. F. Cartwright, T. Dennison, A. Jackson, and C. R. Wheeler. (*Iron Steel Inst., Special Rep.* 57, 1956, pp. 35). A report of a visit.

The Iron and Steel Industry of Japan. Japan Iron and Steel Federation. (*Pamphlet*, 1956, pp. 28). A review, mainly statistical.

All-Welded Construction of a Large Steelworks in Czechoslovakia. G. Novotny. (*Acier Stahl Steel*, 1956, **21**, Apr., 161–168). Plans and illustrations of the steelworks in course of erection are given.

The Iron and Steel Production of Minas Gerais, Brazil in the National Plan. A. Lamari jun. (*Bol. Assoc. Brasil Met.*, 1956, **12**, July, 179–196). [In Portuguese]. The economic development of the Brazilian steel industry is discussed. Large markets are available but the expansion will depend upon meeting the basic needs of power and transport.—P. S.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

A Blast-Furnace with a Volume of 2000 Cubic Metres. N. K. Leonidov. (*Stal*, 1956, Feb., 115–124). Factors taken into account in design are reviewed and all aspects of the installation and ancillary equipment including choice of location are considered in detail.

Rational Distribution of Stock in a Blast Furnace. T. A. Tesch and E. Johansson. (*Eng. Min. Met.*, 1956, **23**, Feb., 61–67). [In English]. A Swedish automatic charging installation at Oxelosund is described. Considerable economies are claimed.

Production of Sintered Ore with Added Lime and its Use in the Blast Furnace. K. Kawanishi. (*Tetsu to Hagane*, 1956, **42**, Mar., 218–220). [In Japanese]. Lime additions up to 5% in sinter burdens containing predominantly pyrites cinders led to better reducibility and to lower slag volumes, flux usage and blast pressures in the furnace.—K. E. J.

On the Combustion Processes in Blast Furnaces. W. von Preen. (*Giesserei, Techn.-Wissensch. Beihefte*, 1956, Sept., (16), 865–868). This article is a discussion of the work of H. Schiffers in previous issues of this journal. A reply is appended. The physical chemistry of the combustion processes is discussed in terms of the following three equations $2C + O_2 \rightarrow 2CO$; $2CO + O_2 \rightarrow 2CO_2$; $C + CO_2 \rightarrow 2CO$, and is partly mathematical.—R. J. W.

Problems of Metallurgy. Academy of Sciences of the U.S.S.R., Moscow, 1953. **Adsorption-Catalytic Theory of the Reduction of Metal Oxides.** G. I. Chufarov and E. P. Tatievskaya. (15–32). [In Russian]. Based on the authors' work and previous publications together with those of others of their school, the adsorption-catalytic theory of the reduction of metal oxides by CO, hydrogen or solid reducing agents is developed. **Complex Reduction and Oxidation of Elements.** A. S. Tumarev. (33–63). This is a comprehensive discussion of the reduction of mechanical mixtures and compounds of different metal oxides, special attention being given to iron. Oxidation processes in similar systems are also dealt with. **On the Question of Regulating Gas Distribution in the Blast Furnace.** A. N. Ramm. (209–216). A design of blast-furnace top is described in which a large-diameter pipe, connected to a set of offtakes at its upper end has its lower end below the stockline. Through this pipe the gas from the central part of the stockline is led out. The charge passes down the outside of the pipe and another set of offtakes is provided for the peripheral gas. The top is so designed that the charge acts as a loose seal between the two sets of offtakes. Charging mechanisms can be of the conventional type. **The Effect of Intensity of Blast-Furnace Smelting on the Rate of Reduction of Iron and Coke Consumption.** A. P. Lyuban and V. G. Manchinskiĭ. (217–231). On the basis of laboratory-scale experimental results and operating experience with some Soviet blast-furnaces, the effect of changes in driving rate and other factors on coke rate are discussed. Operating experience has shown that both with sinter and unprepared charges increasing driving rate leads to lower coke rates. This is contrary to expectation and the reasons for this anomaly are considered. The applicability of small-scale experimental results to blast-furnace practice is critically examined. Considerable possibilities of improving blast-furnace practice are envisaged. **On the Question of Primary Slag Formation in Blast-Furnaces.** L. M. Tyslev. (232–239). Softening curves for iron ores and sinter and manganese ores are presented together with data on slag viscosities. The formation of primary slags is discussed and the zones of the blast-furnace in which this occurs are indicated. **Method of Mineralogical Control of Blast-Furnace Smelting with Manganiferous Slags.** A. V. Rudneva. (240–252). The mineralogy and related properties of manganese-containing slags are described and some examples of the application of mineralogical examination to the elucidation of various features of blast-furnace smelting processes are given. **Investigations of the Blast-Furnace Process.** A. D. Gotlib. (253–261). Post-war research work on the blast-furnace process carried out in the Ukraine is described, on the basis of which practice there has been improved. **Experience in Smelting Low-Carbon High-Phosphorus Ferromanganese in a Blast-Furnace.** A. L. Zagyanskiĭ. (262–275). Heat and materials balances for the blast-furnace production of ferro-manganophosphorus with low carbon contents (0·5–2% C approx.) are presented for various practices and the mutual effects of variation on the contents of components are discussed.—S. K.

Effect of Increased Pressure of Blowing on Pig-iron Composition. V. L. Pokrychkine. (*Centre Doc. Sidér. Circ. Inform. Tech.*, 1957, **14**, (1), 3–15; translated from *Stal'*, 1956, **16**, June, 487–492).

Permeability Test on Blast Furnace Burdens. M. Kawamura. (*Tetsu to Hagane*, 1956, **42**, Mar., 224–225). [In Japanese]. Test results show the changes in permeability caused by changes in burden size, removal of fines or lumps, and changes in burden voidage for two types of ore, sinter, open-hearth slag and coke.—K. E. J.

Study of the Heat Balance and the Formula for Calculating the Coke [Rate] in the Blast Furnace. K. Segawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 220–222). [In Japanese]. Formulæ and a nomogram are given for obtaining the coke rate in terms of iron make, furnace capacity, coke quality (ash%), top-gas analysis, iron content of the ore, and a furnace volume factor.—K. E. J.

On the Relation between Top-Gas Analysis and Blast Furnace Operation. A. Tayama. (*Tetsu to Hagane*, 1956, **42**, Mar., 228–229). [In Japanese]. A statistical investigation is made into changes of silicon content in the iron with the CO/CO_2 ratio for different temperature conditions.—K. E. J.

Influence of Manganese on the Desulphurization of Pig-iron. R. A. Hacking and C. E. A. Shanahan. (*Iron Coal Trades Rev.*, 1956, **173**, Dec. 14, 1427–1432). The authors consider the techniques for removing sulphur from pig-iron before it reaches the steelmaking furnace, with special reference to the influence of manganese. They outline the general theory of desulphurization by slags, and discuss desulphurization within the blast furnace, in the casting ladle, and in the active and inactive mixer.—G. F.

Theoretical Study on the Effect of Reducibility and Particle Size of the Ore on the Productivity of the Blast Furnace. K. Segawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 222–223). [In Japanese]. The maximum production rate is deduced from considerations of ore size, reducibility and resistance to flow of the burden. Data from an experimental and an operating furnace are used to demonstrate a relationship between (*a*) the ratio of furnace volume below the shaft to production rate, and (*b*) the product of shaft volume, coke rate and the reciprocal of the ore reduction time.—K. E. J.

Investigations for Testing the Behaviour of Ores in the Blast Furnace. J. Willems, P. Dickens, and W. vor dem Esche. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1404–1409). The authors studied the high-temperature behaviour of 33 types of ore, three sinters, and 12 pellets by a method similar to that used for the appraisal of refractories for predicting the reducibility in the blast furnace. Cylinders or tubes ($a = 50$ mm) were heated at a rate of 8° C/min under a pressure of 2 kg per cm². Expansion/time curves were taken, and the beginning and end of the softening temperature measured. The changes taking place on heating specimens 7 mm long were observed in a hot-stage microscope up to 1600° C and sinter-, softening-, flow-, and melting points determined. Finally the change in the softening point on heating the sample in air and CO, O_2, and N_2 was studied. The results obtained are presented in tables and graphs.—T. G.

The Causes of Blast-Furnace Explosions and Recommendations for Design and Operation of Blast Furnaces. W. Feldmann. (*Stahl u. Eisen*, 1956, **76**, Nov. 15, 1541–1553). The causes of two blast-furnace explosions—at Dillingen in July 1955 and at Hörde in November 1955—are analysed. In both cases true explosions occurred. Their causes are attributed to: faulty tuyeres, leaky gas pipes, heavy wear of the lining, carbon deposits, scaffolding, and the presence of highly active carbon (resulting from the decomposition of carbon monoxide), etc. Both furnaces were equipped with loop-type armour. The author recommends that, in future, only fully armoured furnaces be built as these would withstand the pressure of any explosion occurring in the furnace. In the discussion a number of theories on the cause of blast-furnace explosions were put forward; some of them were disputed.—T. G.

Experimental Study on Oxygen in Pig Iron. Y. Takahashi. (*Tetsu to Hagane*, 1956, **42**, Mar., 236–237). [In Japanese]. Investigations are reported into the effects on oxygen content of coating materials and water cooling, remelting pig iron with scrap and scale, and the FeO content of the slag.—K. E. J.

Oxygen Lancing of Pig Iron and Subsequent Fume Treatment with a Pease-Anthony Venturi Scrubber at Dorman Long (Steel) Ltd., Redcar. P. K. Gledhill, P. J. Carnall, and K. H. Sargent. (*J. Iron Steel Inst.*, 1957, **186**, June, 198–211). [This issue].

Low-Shaft Furnaces as an Alternative to the Blast Furnace. A. B. Chatterjea. (*Iron Coal Trades Rev.*, 1956, **173**, Nov. 23, 1255–1261; Nov. 30, 1329–1335). The author considers the potentialities of low-shaft furnaces as an alternative to normal blast furnaces in an integrated plant. He surveys the design and operation of existing low-shaft furnaces, and discusses the thermal efficiency and the equilibrium relations of these units. He concludes that the low-shaft furnace can replace the normal service only in countries possessing low-grade ores and fuels.—G. F.

A New Approach in Electric Pig Iron Smelting. F. C. Collin and O. A. Grytting. (*J. Met.*, 1956, **8**, Oct., Section 1, 1464–1468). The possibility of using the Tysland-Hole furnace top gas to preheat and pre-reduce the ore, with consequent reduction in electric energy requirements in the furnace, has been studied by many investigators without complete success. The authors describe a new approach developed in Norway, where a rotating kiln continuously feeds the hot, pre-reduced charge by gravity, directly into the electric furnace. Experimental results are discussed and the application of the new practice is considered.—G. F.

Study on the Manufacture of Special Pig Iron and High-Titanium Slag from Titaniferous Iron Ores. A. Fukuda. (*Tetsu to Hagane*, 1956, **42**, Mar., 174–176). [In Japanese]. The compositions of the iron ores varied from Fe (total) 59·79% and TiO_2 8·9% to Fe (total) 38·53% and TiO_2 38·84%; full analyses are given. The irons produced had analyses varying as follows: Si 0·07%, S 0·005–0·011%, P 0·105–0·14%, Mn 0–0·65%, Cu 0–0·04% and Ti trace. The TiO_2 content in the slags varied between 86·07 and 92·02%.—K. E. J.

Influence of Slag Properties on Pig Iron Composition. A. J. Burgess and B. G. Baldwin. (*J. Iron Steel Inst.*, 1957, **186**, June, 227–235). [This issue].

Considerations on the Superheating of Molten Cast Iron. M. Homma. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Aug., 371–374). [In Japanese]. Superheating influences mainly the elimination of dissolved oxygen by carbon. The fine graphite structure of superheated iron is caused by supercooling of the melt accompanied by deoxidation, not by solution of graphite nuclei. (13 references).—K. E. J.

Experimental Research on Superheating of Molten Cast Iron. M. Homma and Y. Hashimoto. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Aug., 375–378). [In Japanese]. Specimens were melted between 1200° and 2000° C in a CO atmosphere in a Tammann furnace. As the temperature rises, the graphite structure is refined, in a similar way to that produced by melting at 1350° C with reducing slags. With superheated melting, a fine granular graphite structure appears, regardless of the chemical composition.—K. E. J.

TREATMENT AND USE OF SLAGS

Some Characteristics of Blast Furnace Slags Containing Chromium. Y. Matsushita. (*Tetsu to Hagane*, 1956, **42**, Mar., 173–174). [In Japanese]. Slags of varying basicity containing chromium were examined by spectrophotometer after heating *in vacuo* at various temperatures. Evidence is put forward for the existence of Cr^{++} and CrO_3^{----} ions.—K. E. J.

Classification of Particle Shape in Washed and Crushed Blast-Furnace Slag, with Particular Reference to the Crusher. H. Kahlhöfer, A. Send, and H. Kaiser. (*Stahl u. Eisen*, 1956, **76**, July 26, 957–964). Methods of classifying particle shape are reviewed and quantitative criteria compared. A description is given of investigations on blast-furnace slag at the Mannesmann works. The effect of crusher design on the quality of the crushed material is discussed. Allusion is made to the interrelation between particle shape, density, and ability to withstand pressure.

Measurements of Densities of Molten Silicates. S. I. Popel' and O. A. Esin. (*Zhur. Priklad. Khim.*, 1956, **29**, (5), 651–655). [In Russian]. Density measurements of molten silicate systems (FeO–SiO_2, FeO–SiO_2–CaO, and CaO–SiO_2–Al_2O_3) relevant to blast-furnace and steel-making slags at 1400° C were carried out. The method of determination was based on the measurement of the maximum pressure during the formation of bubbles at the end of a tube (6 mm dia.) dipped into the melt to different depths. The apparatus used is described.—V. G.

Behaviour of TiO_2 in Slags. K. Sawamura. (*Tetsu to Hagane*, 1956, **42**, Mar., 172–173). [In Japanese]. The effects of TiO_2 added to blast-furnace slags in amounts up to 7% on the percentage of sulphur in metal are investigated at 1450°, 1500°, and 1550° C. Desulphurization curves are given for the metal under slag containing 1% of TiO_2 for periods up to 150 min at the same temperatures.—K. E. J.

PRODUCTION OF STEEL

Several Problems in Oxygen Practice in Iron and Steel Making. K. Endo. (*Tetsu to Hagane*, 1956, **42**, July, 579–590). [In Japanese]. Applications of oxygen in open-hearth furnaces, converters and low-shaft furnaces are surveyed in the light of American and Continental results, and confirmatory data from experimental installations are adduced. (33 references).—K. E. J.

Tonnage Oxygen: Pressure Under a Big Market. J. J. Obrzut. (*Iron Age*, 1956, **178**, Oct. 4, 91–93). Estimates of the oxygen requirements of the U.S. steel industry over the next 10 years are given. The growth of processes requiring oxygen is considered; these include scarfing, steelmaking techniques, and blast furnace enrichment.—D. L. C. P.

The Effects of the Methods of Deoxidising on Steel Quality. I. T. Horigome. (*Tetsu to Hagane*, 1956, **42**, Mar., 328–330). [In Japanese]. The effects on an experimental and a 500-kg ingot of adding aluminium in amounts up to 0·1%, in the mould, in the ladle, and under the nozzle, are investigated.

Equilibria in Reactions of Hydrogen, and Carbon Monoxide With Dissolved Oxygen in Liquid Iron; Equilibrium in Reduction of Ferrous Oxide With Hydrogen, and Solubility of Oxygen in Liquid Iron. N. A. Gokcen. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Nov., 1558–1567). Equilibria in the range 1550–1700° C have been investigated for the reactions between dissolved oxygen in liquid iron and both hydrogen and carbon monoxide, and between hydrogen and liquid wüstite, and have indirectly enabled the solubility of oxygen in liquid iron to be obtained with a high degree of accuracy. The results are expressed in thermodynamic functions, and correlated with new data on the standard free energies of H_2, H_2O, O_2, and CO_2.—G. F.

Thermal Behaviour of Sulphides in Steel. M. Nakamura. (*Tetsu to Hagane*, 1956, **42**, Mar., 333–334). [In Japanese]. Data are given to show that the ratio of sulphur in FeS to total sulphur falls with heating, as temperatures are raised from 800 to 1200° C and heating times are increased up to 6 hours, in steels containing approx. 0·085% of sulphur and manganese in the range 0·5–2·5%.—K. E. J.

The Desulphurisation of Iron and Steel. J. Vázquez López. (*Anal. Mec. Elect.*, 1955, **32**, May-June, 115–125). A review.

Rate and Mechanism of the Sulfur Transfer Reaction. S. Ramachandran, T. B. King, and N. J. Grant. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Nov., 1549–1558). The authors have measured the rate of sulphur transfer between carbon-saturated iron and oxide slags, using an apparatus permitting concurrent measurements of CO evolution, and have also observed the movements of other elements. The results indicate that an electrochemical mechanism is possible, and the mode of CO evolution is clarified by treatment of the results in terms of the two-film hypothesis of reactions between two liquid phases.—G. F.

Rate of Desulphurization of Molten Iron by Slag under Reducing Conditions. II. Influence of Silicon and Manganese. Y. Kawai. (*Sci. Rep. Res. Inst. Tohoku Univ.*, 1956, **8A**, Aug., 352–360). The range 1490–1560° C was investigated and the rate was found to increase with increasing Si and Mn. The mechanisms are discussed.

Sulfur Equilibria Between Gases and Slags Containing FeO. G. R. St. Pierre and J. Chipman. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section I, 1474–1483). The authors have studied sulphur equilibria in FeO slags with additions of CaO, SiO_2, and MgO, equilibrated with SO_2 atmospheres containing CO and oxygen. At low and high oxygen partial pressures, sulphur is present as sulphide and sulphate respectively. At constant sulphur and oxygen pressures, sulphur absorption as sulphide is nearly independent of CaO/FeO ratio but is decreased by SiO_2 or MgO addition. Absorption as sulphate requires the presence of CaO.—G. F.

Hydrogen in Molten Steel. III. Analysis of Hydrogen in Steelmaking Slag. S. Sawa. (*Tetsu to Hagane*, 1956, **42**, Aug., 638–647). [In Japanese]. Studies were made of methods employing vacuum heating to 1200° C and vacuum melting at 1800° C. Hydrogen in steelmaking slag can only be extracted completely by heating to above 1400° C. In a graphite crucible, water is quantitatively decomposed and extracted as hydrogen. A molybdenum crucible is preferable for vacuum fusion work, to avoid reactions with the crucible.

Review of Certain Iron and Steel Making Developments. F. De Carli. (*Calore*, 1956, **27**, May, 199–209). [In Italian]. The author reviews the principal developments which have taken place in the iron and steel industry in the course of the last ten or fifteen years. Amongst the developments described are: pelletization, suspended O.H. roofs, the use of

basic refractories, the increased productivity of furnaces, the uses of oxygen, the L.D. steelmaking process, vacuum casting, the use of large electric steelmaking furnaces, and the continuous casting of steel.—M. D. J. B.

Some Achievements of Modern Metallurgy. H. K. Worner. (*J. Australian Inst. Met.*, 1956, **1,** Oct., 69–75). The Presidential address to the Institute.

Problems in Steelmaking: Discussions at 10th BISRA Junior Steelmaking Conference. (*Iron Coal Trades Rev.*, 1956, **173,** Sept. 28, 785–792). A summary is given of the proceedings of B.I.S.R.A.'s 10th Junior Steelmaking Conference. The subjects discussed were top and bottom pouring practice, open hearth refractories, and the comparative economics of electric and O.H. furnaces.—G. F.

The Role of the Supervisor. R. P. Billimoria. (*Tisco*, 1956, **3,** Oct., 182–188). The author discusses typical problems encountered by a supervisor in the Tata Iron and Steel Co. and suggests, where possible, the solutions to such problems. The question of morale, the functions of the 'formal' and 'variant' organizations, the role of statistics etc. are considered.—L. E. W.

Half-Wagon for Transporting Scrap. A. P. Vikhrev and A. I. Mukhaev. (*Stal'*, 1956, (5), 471). [In Russian]. A brief description is given of a type of wagon developed at the Kuznetsk Metallurgical Combine for the internal transfer of scrap. Wagon capacity is 40–45 tons of light scrap.—S. K.

Kuznetsk Combine in the Sixth Five-Year Plan. B. N. Zherebin. (*Stal'*, 1956, (5), 389–390). [In Russian]. Recent successes and failures at the major Soviet Siberian steel centre and the planned future growth of production are discussed.

Recent Trends in Design and Equipment of a Modern Steelmelting Shop in the United States. P. Anant. (*Tisco*, 1956, **3,** Oct., 189–193). The author describes the general layout of a modern steelmelting shop and shows how improvements in design and equipment have been made. Recent advances in the U.S.A. in mixer, converter and basic open-hearth practices are discussed.—L. E. W.

The Production of Medium-Strength Steel in the Surface Blow Converter. K. Rösner and A. Wegscheider. (*Stahl u. Eisen*, 1956, **76,** Oct. 18, 1337–1343). The process of surface blowing with oxygen-enriched air has hitherto been mainly employed for the production of mild steel but it is equally suitable for the production of medium-strength steels such as high-carbon steel, railway rail, unalloyed heat-treatable steels, etc., as has been shown in Donawitz. The authors describe the processes used in the production of these steels: (*a*) addition of pig iron from the holding furnace after the carbon of the charge has burnt down to 0·08% (*Nachleerverfahren*); (*b*) stopping blowing after 16–17 min during the manganese reduction (*Fangschmelzenverfahren*); (*c*) similar to (*a*) but using pre-blown iron high in carbon and very low in Mn, P, S, and N; and (*d*) similar to (*b*) but with slag removal after 8–10 min blowing. The processes used and the analyses and characteristics of the steels obtained are discussed in detail.

The Oxygen Converter Process. J. Doi. (*Tetsu to Hagane*, 1956, **42,** Apr., 344–356). [In Japanese]. The production of steel by oxygen blowing in converters is reviewed, with special reference to practice in Canada and Austria. Details are given of the converters used, plant layouts, heat balances, and compositions, properties and uses of the steels; the process is compared with the open-hearth process in respect of capital costs, material costs and operating costs, and shows a favourable result. (38 references).—K. E. J.

The Use of Oxygen in Iron and Steel Production. D. J. O. Brandt. (*West Scotland Iron Steel Inst., Paper No.* 496, Nov. 23, 1956, pp. 22). The author surveys current practice and its application to British conditions. The uses of oxygen are considered with reference to the normal blast furnace, the low-shaft blast furnace, pre-refining, converter blast enrichment, mixed blast converters, and the L–D converter. The roles played by oxygen in O.H. and electric furnace steelmaking processes are dealt with. The author concludes by mentioning economic factors and recent developments such as desiliconization—L. E. W.

Use of Oxygen in Steel Manufacture. F. Johansson. (*Jernkontonets Ann.*, 1956, **140,** (9), 607–673). [In Swedish]. A general review is made of the advantages and hazards attendant upon the use of pure oxygen in steelmaking, existing methods being critically assessed. Consumption data are presented for different Swedish and foreign plants. Details are given of the new Austrian LD process, now in full-scale use, and its future importance is stressed. Advantages of the Kalling-Domnarfvet process, in which the oxygen is introduced into a rotating furnace, are reviewed as compared with the LD process. The ensuing discussion contains details of Swedish experience with the use of oxygen.—G. G. K.

One Million Tons of Steel Produced by Blowing Oxygen into Iron. R. Rinesch. (*Met. Ital.*, 1956, **48,** April, 153–159). [In Italian]. This article describes in detail the L.D. process at the Voest Works in Austria. Details are given of the converters and their linings, the method of blowing oxygen and the 1000 ton hot metal mixer. Technical and metallurgical data of the change are also given, in particular the composition of the iron, and the contents of Si, Mn, P, S, N and O, as well as of additions of lime, bauxite, iron oxide and scrap. Production programmes and the timing of operations are discussed.—M. D. J. B.

Economics of Oxygen. (*Steel*, 1956, **139,** Nov. 5, 114, 117). Notes on costs are given.

Developments in Open-Hearth Furnace Layout: Russian Block System for 500-ton Furnaces. (*Iron Coal Trades Rev.*, 1956, **173,** Sept. 7, 635–636). Russian plans for increasing steel production include the installation of 500-ton O.H. furnaces in a block system, where the furnaces are placed in blocks of two with direct access from the blast furnaces. The advantages of the system are outlined and the dimensions of the furnaces are given.—G. F.

Electric Open Hearth Combustion Controls at Algoma. A. K. Bayles and D. M. Stanton. (*Iron Steel Eng.*, 1956, **33,** Oct., 143–147). Equipment for two 330-ton O.H. furnaces is reviewed.

The Deflection of Hot Jets due to Buoyancy. F. A. Gray and A. D. Robertson. (*J. Inst. Fuel*, 1956, **29,** Oct., 424–427). Tests are described from which a simple empirical relationship is derived, on which to assess the effect of buoyancy in furnaces. This may be used as a first approximation to indicate the error introduced by neglecting the effect of buoyancy in isothermal models.—D. L. C. P.

Injection of Air into O.H. Furnace Ports. L. S. Klimasenko, M. Ya. Medzhibozhskiĭ, E. I. Korochkin, N. I. Bovin and D. Z. Savostin. (*Stal'*, 1956, (5), 462–463). [In Russian]. Injection of compressed air into the gas ports of 380-ton O.H. furnaces at the Kuznetsk Metallurgical Combine decreased tap-to-tap time by 30–40 min and resulted in some fuel economy.—S. K.

Open Hearth Combustion Controlled by Continuous Waste Gas Analysis. F. S. Swaney. (*Indust. Heating*, 1956, **23,** Oct., 2092–2094). The sampling system and the conditioner and analyzer are described, the oxygen being recorded by its paramagnetism.

Accelerating Open-Hearth Furnace Repairs. H. Haniš. (*Hutník*, 1956, **6,** (7), 194–197). [In Czech]. Details of the organization and rationalization of repair work are given and illustrated with data obtained in the course of works applications.—P. F.

Electromagnetic Stirring—Application to Desulphurization. J. Duflot and M. Porcheray. (*Met. Ital.*, 1956, **48,** March, 101–110). [In Italian]. This article describes a method of electromagnetic stirring developed by ASEA and applied at the Hagondange Works of the Société des Aciers Fins de l'Est. Details are given of the equipment used, of the techniques and methods followed and of the results obtained over a long period of exhaustive tests conducted with and without stirring of the bath. Considerable statistical data in table form are given.—M. D. J. B.

Developments in the Construction of Hot Metal Mixers. P. Devidts. (*Met. Ital.*, 1956, **48,** Sept., 413–414). [In Italian]. The author gives brief notes regarding the construction of a hot metal mixer in Lorraine. The mixer has a capacity of 1000 tons. Special precautions were taken to ensure the best possible heat insulation—M. D. J. B.

Production Costs of Steel. Open Hearth and Electric Processes. P. Allarme, H. Bailleul, A. Cella, A. De Negri, R. Dupuis, A. Ferro, L. Lazzeri, G. Morini, P. Nigri, V. Oddono, M. Palazzuoli, L. Tagliabue, L. Tagliaferri, G. Verzi and A. Martone. (*Met. Ital.*, 1956, **48,** May, 193–258). [In Italian]. This paper makes a detailed study of O.H. and electric steelmaking processes. The subjects specifically covered are: a review of the Italian iron and steel industry, factors affecting production costs, a comparative study of open hearth and electric arc furnaces, the production of tonnage steel, heat and material balances, a detailed economic study of capital investments, of the cost of materials both metallic and non-

metallic, of conversion costs and of production costs, a study of steel qualities and finally a study of raw materials, refractories, fuels and power. (74 references).—M. D. J. B.

The Investigation of Fluid Flow Problems by Model Techniques. F. A. Gray and A. D. Robertson. (*J. Inst. Fuel*, 1956, **29,** Oct., 428–437). Nunerous aspects of the investigation of gaseous flow systems by models are described including studies on burners and furnaces. Calibration of meters is included.

The Changing Open Hearth Picture. K. C. McCutcheon. (*Blast Furn. Steel Plant*, 1956, **44,** Dec., 1411–1416). The work of the Technical Committee on O.H. Steelmaking Practice is mentioned and a review presented of the improvements in operation since its inception. Work in progress is briefly outlined.

Many Year's Operating Experience with a Mixer. G. N. Susakin. (*Stal'*, 1956, (5), 465–467). [In Russian]. The operation of a 1200-ton mixer over a prolonged period is analysed, details being given of repairs. Lining wear is determined by measuring the shell temperature at various points.—S. K.

Rational Method for the Preliminary Deoxidation of Steel. N. I. Shirokov, B. G. Petukhov and A. I. Borodulin. (*Stal'*, 1956, (5), 415–422). [In Russian]. Experiments on 380- and 190-ton basic O.H. furnaces producing rail and other steels are described in which three methods of deoxidation in the bath were compared. The use of blast-furnace ferrosilicon for preliminary deoxidation was found to lead to loss of productivity, increases in the phosphorus and hydrogen contents of the steel, and increased cost. For rail steel the use of ferromanganese alone enabled productivity to be increased by 2–2·5% with improved metal quality and lowered costs. Similar advantages were obtained for low-carbon steel from the use of ferromanganese alone instead of silicomanganese and blast-furnace ferrosilicon and for medium carbon steel by using ferromanganese followed by addition of 45% ferrosilicon and aluminium in the ladle.—S. K.

Deoxidation of Steel with Silicon and Manganese. I. S. Kulikov and A. M. Samarin. (*Izvest. Akad. Nauk S.S.S.R. Otdelenie Tekn. Nauk*, 1954, Oct., 23–30). Thermodynamic equations are given and equilibrium constants determined. Activities for the oxides at 1550° C are shown in terms of concentration and measured values compared with the theoretical curve. Absence of interfacial tension measurements complicates the interpretation in practical terms.

The Production of Transformer Steel by a Duplex Method Using Open-Hearth and Electric Furnaces. K. Hýbek and F. Pobořil. (*Hutnické Listy*, 1956, **9,** (9), 529–532). [In Czech]. Factors affecting the quality of transformer steels are surveyed. Production technology and quality tests as used in connection with the open-hearth electric arc furnace process are described with special reference to results obtained in recent years in the Molotov Steelworks in Třinec, Czechoslovakia.—P. F.

Use of Beneficiated Apatite for Phosphate Enrichment of Duplex Slag—Production of Ferro-phosphorus and Thermal Phosphate. A. B. Chatterjea and B. L. Nijhawan. (*J. Sci. Indust. Res.*, 1956, **15B,** June, 311–315). Beneficiated apatite cannot be used in an arc furnace for the manufacture of ferro-phosphorus owing to loss of phosphorus by volatilization, or in a basic open hearth furnace for the manufacture of phosphate fertiliser. However, with suitable additions of serpentine and silica in an arc furnace, apatite will produce a phosphate slag.—E. E. W.

Electric Furnace Steel Conference 1955. Amer. Inst. Mining and Met. Eng. (*Pittsburg, Proceedings of 13th Conference*, pp. 239). **Improvement of Human Factors in Electric Furnace Operations.** W. Exton, jun., (14–54). An address in three parts: I, Motivation of production efficiency. II, The electrode story. III, The electrode joint. A programme of training and its effects with special reference to electrode economy is outlined. Particulars of the course with the diagrams used and the points dealt with are given. **Hydrogen Control through Flushing of Molten Steel in Electric Arc Furnaces.** L. F. Bernhardt, (58–69). Nitrogen, argon, and dry air are used. Dry air can be used except for Stainless 321, valve steels and Magnaflux aircraft quality where argon is necessary. Effects in a 30-ton furnace are summarized. In discussion, practice at Armco, the porous plug method, and other topics are touched on. **Factors Affecting Cleanliness of Low-alloy Steels.** H. C. Bigge, (85–103). These are discussed briefly beginning with scrap preparation and inspection and the drying of raw materials. Lime and petroleum coke analyses are given. The discussion ranges over many aspects of steel making. **Molten Steel Splash Patterns in Ingot Teeming as Revealed by High-speed Motion Pictures.** A. B. Blockside, jun., (104–109). The method is described and equipment shown. Discussion of the films and results of volatility tests with tar-like and pitch-like castings are shown. **Quality Control of Melting Practices.** H. H. Johnson and G. A. Fisher, (150–165). Various compositions, temperatures, and abnormal heats are shown over several months of operation and control charts are shown. **Ferrochromium Charge.** A. K. Blough, (181). **Effect of Medium and High-carbon Ferrochromium in the Charge on Stainless Melting Practice.** L. G. Cotton, jun., (182–185). **The Melting of Stainless Steel—the Reducing Period.** L. F. Weitzenkorn, (192–194). Armco Steel Corp. practice is described. **Slag-Reducing Agents in the Making of Stainless Steel.** B. H. Brown, (194–195). The use of ferrochromium–silicon is described. **Slag Reduction in the Melting of Stainless Steel.** D. J. Carney, (196–199). **Deoxidizers and Tapping Temperatures.** H. M. Parker, (200–201). **Deoxidation and Temperature Control in Stainless.** C. Yutmeyer, (201–205). **Comparisons of Acid and Basic Electric Melting Practice for Mild and High-tensile-strength Steel Castings.** W. Tibbits. (206–210; discussion 210–221). Furnace construction is outlined. **How Will We Charge Tomorrow's Furnaces?** E. J. Hanley, (227–232). Economic and other trends are considered in the closing address.

Contributions to Arc Furnace Operations. L. A. Wynd. (*Iron Steel Eng.*, 1956, **33,** Oct. 135–142). Current feeder systems and controls are discussed and equipment used by Republic Steel Corp is listed.

Bath Stirring in Steel Manufacture. Mechanical versus Inductive Stirring. A. Faerden. (*Tidsskr. Kjemi, Bergvesen, Met.*, 1956, **16,** (7), 118–125). [In Norwegian]. After discussing developments in the electrical production of steel and stirring methods usually employed in arc furnaces, the author deals with mechanical and inductive stirring together with the use of gases and metal vapours. A comparison is made between stirring costs with both methods for a 30 ton furnace with an output of 45,000 tons/year and the conclusion is drawn that under certain conditions inductive stirring, which gives continuous bath movements, will result in a quicker refining process.—G. G. K.

Special Steels and Alloys. G. T. Harris. (*Research*, 1956, **9,** Sept., 335–346). A general account is given with compositions, properties and uses. Stainless and high temperature steels and titanium alloys are included.

Steels with High Workabilities. L. Ribotti. (*Met. Ital.*, 1956, **48,** April, 109–112). [In Italian]. The author discusses briefly the characteristics, both chemical and mechanical, of steels with a high degree of workability and suggests certain norms which will ensure that these properties are achieved.

Production of Rail Steel from Low-Manganese Pig Iron without Addition of Ferromanganese during the Boil. E. Ya. Zarvin, N. S. Mikhaĭlets and K. V. Demykin. (*Stal'*, 1956, (5), 431–437). [In Russian]. Experiments at the Kuznetsk Metallurgical Combine have confirmed that good quality rail steel can be produced without the addition of ferromanganese towards the end of the ore boil, in the O.H. furnace, even though low-manganese pig iron is used. Some general conclusions on the role of manganese in the steel-making process have been drawn.—S. K.

Practical Metallurgical Problems in the Field of High Temperature Steels. W. Siegfried. (*Métaux-Corrosion-Indust.*, 1956, **31,** Oct., 418–431). A comprehensive review of the properties of alloys suitable for use at high temperatures is given. The properties of a large number of ferritic steels developed in Europe and of 15 austenitic alloys are given in tabular form. The creep resistance properties of a number of high temperature alloys are given in a series of graphs. The properties required at high temperatures are discussed.

Low-alloy Steels for Welded Pressure Vessels. (*Iron Coal Trades Rev.*, 1956, **173,** Oct. 26, 1021–1025). A review is given of the technical sessions at a recent West of Scotland I.S.I. symposium on low-alloy steels for welded pressure vessels. The composition and treatment of some of these steels are discussed, and the questions of weldability and pressure-vessel design are considered.—G. F.

High-tensile Weldable Steel: Development of a Mn–Cr–Mo–V Type for Pressure Vessels. W. Barr and I. M. Mackenzie.

(*Iron Steel*, 1956, **29**, Nov., 519–522). The authors describe the development of "Ducol W.30," a semi-air-hardening high-tensile Mn–Cr–Mo–V steel for use in welded pressure vessels. The properties of the steel, in particular, its tensile properties and weldability, are discussed, and its response to heat treatment is described.—G. F.

Rare Earths in Steel Castings. W. J. Jackson. (*Metallurgia*, 1956, **54**, Nov., 233–238). Comparatively little attention has been given to the application of the rare earths in cast steels, but from the limited published work on the subject it would appear that rare-earth additions improve ductility and impact properties, reduce susceptibility to hot tearing, and increase fluidity. Both hardenability and weldability appear to be unaffected. (22 references).—B. G. B.

Influence of the α-Phase on the Quality of Stainless Sheet. R. P. Radchenko. (*Stal'*, 1956, (5), 450–452). [In Russian]. In the investigation described the distribution of the α-phase in a stainless steel ingot for various heating temperatures and the influence of the phase on the quality of the sheet were studied. For the steel used (1Kh18N9T) a temperature $< 1250°$ C is recommended.—S. K.

Some Considerations on the Occurrence of Sand Marks. J. Watanabe *et al.* (*Tetsu to Hagane*, 1956, **42**, Mar., 324–325). [In Japanese].—K. E. J.

Study of the Nature and Distribution of Non-Metallic Inclusions in Ingots of Rimming, Mild, Open-Hearth Steel. H. Hoff, H. Lessing, and G. Masing. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1442–1452). Quantity, nature, grain-size, and distribution of non-metallic inclusions in 5-ton ingots of rimming steel poured by various processes were studied by the isolation methods of Kuschmann and von der Donk and of Klinger and Koch. Shape, colour, weight, density, and chemical analysis of the separated inclusions obtained by the two methods differ from each other considerably. Microscopical, optical, and X-ray examinations were made. The results are presented in graphs and tables and in two colour plates.—T. G.

PRODUCTION OF FERROALLOYS

Ferrosilicon Manufacture at Marietta. E. E. Thum. (*Metal Progress*, 1956, **70**, Oct., 65–72). A description is given of the plant and practice for the electric furnace smelting of ferrosilicon at the Marietta works of the Union Carbide and Carbon Corporation.—B. G. B.

Impurities in Ferro Alloys. IV. Impurities in Tungsten Alloys. H. Willners and K. A. Ottander. (*Monograph of Swedish Ironmasters' Association*, Stockholm, 1956, Translation). Notes on segregations, slag inclusions, impurities in the form of metals and metalloids, and gases are discussed and tabulated. Fe–W, W–C, Fe–W–C and Fe–W–FeSi diagrams are given and other elements are considered. (24 references).

Anodic Solution of Ferrochromium in Solutions of Sodium Carbonate and Sodium Hydroxide. R. I. Agladze and T. V. Ionatamishvilli. (*Zhur. Priklad. Khim.*, 1956, **29**, (9), 1365–1372). [In Russian]. Optimum concentrations of sodium carbonate and sodium hydroxide as well as optimum current densities and temperatures for both electrolytes were determined. Sodium hydroxide is superior to sodium carbonate for anodic solutions of chromium, since the consumption of current is lower and under certain conditions the precipitate of ferric oxide is easy to filter and chromium losses with the precipitate are at a minimum.—V. G.

FOUNDRY PRACTICE

Cast Iron and Steel Castings at the Industrial Fair 1956 in Hannover. W. Schumacher. (*Giesserei*, 1956, **43**, June 21, 340–345). Exhibits of interest to the foundryman are described first in general terms and then some items in detail. The article is well illustrated. Several very large castings to be used as baseplates for various equipments are shown. Among other items of interest are large centrifugally-cast tubes and examples of the welding of spheroidal graphite cast iron.

Proposals for Inquiries on Jobbing Casting. W. Hagedorn. (*Giesserei*, 1956, **43**, June 21, 351–352). The essential estimating for inquiries on jobbing casting is reviewed in detail, and the best manner to obtain a favourable price estimate discussed. The economics of different pattern methods in relation to the number of castings made is illustrated graphically. Similarly, the variation in the total cost of a casting with the number made is shown.—R. J. W.

Compilation of Work Preparation and Cost Estimation Data for the Hand-Moulding of Medium and Large Size Castings. F. Lamm. (*Giesserei*, 1956, **43**, Aug. 30, 587–591). The difficulties encountered in the fabrication of one-off jobs are described. A job analysis is given together with a determination of the time consumed per piece. The establishment of reference values and data is described: time studies are summarized. The method of calculating the efficiency is also described and numerical examples given.—R. J. W.

The Dilatation and Oxidation of Cast Iron. S. Valente. (*Fonderia Ital.*, 1956, **5**, Mar., 81–88). [In Italian]. The results are given of experimental researches conducted to determine quantitatively the parts played by oxidation, graphitization, and irreversible thermal expansions in the growth of cast irons.—M. D. J. B.

The Transport Problem in the Iron Foundry. C. Stieler. (*Giesserei*, 1956, **43**, Sept. 13, 622–625). The economics and efficiency of an iron foundry stand or fall on the solution of the conveying problem. The reduced conveying capacity of moulds by replacing cast-iron moulding boxes by aluminium or steel is considered. Numerical examples are given. The partial mechanization of a grey iron foundry is described.

Analytical Qualifications required in the Foundry. D. Freiling. (*Giesserei*, 1956, **43**, Sept. 13, 625–627). A discussion on different working methods in the foundry. The qualifications necessary for the satisfactory running of a foundry are analysed and tabulated in different forms. Proposals are made for separating the various requirements, e.g. knowledge, load, justification and working conditions. Psychological aspects are also considered.—R. J. W.

Design, Construction and Running of a Water-cooled Balanced-blast Cupola and its Performance Compared with a Similar Brick-lined Cupola. W. Y. Buchanan. (*Found. Trade J.*, 1956, **101**, Nov. 1, 497–508). The design and erection of a 45-in. diameter water-cooled Balanced-Blast cupola is described. The cupola is cooled at the tuyere zone, in the melting zone, and at the charging zone. The operation and performance of the cupola is compared with that of an identical uncooled Balanced-Blast cupola particularly in regard to metal temperature, melting rate, consumption of patching material, and metal fluidity. Initially the metal temperatures obtained with the water-cooled cupola were low but the use of oxygen enrichment in the blast, the introduction of an air weight controller and the use of a warm blast gave increased temperatures and improved fluidity. The author reports that the water-cooled cupola is now giving excellent results.—B. C. W.

Fully Automatic Conveying Systems for the Production of Cast Heating Radiators with Modern Charging and Hot-blast Cupola Plants. F. Grosser and O. Reif. (*Giesserei*, 1956, **43**, Aug. 30, 463–473). The melting shop and the layout of the whole plant used for the production of radiators is described. A mechanized line for the production of radiators of medium height is described in detail. Included in the line are sand beneficiation, continuous core-drying and hot-blast melting plant. Another mechanized production line, for radiators with 1000 mm between the bosses is described. Line drawings show the different lay-outs.—R. J. W.

The Jungbluth Reticule Diagram and Material Reactions in the Cold-blast Cupola. W. Patterson. (*Giesserei*, 1956, **43**, Aug. 30, 486–497). The Jungbluth diagram is described and its range of validity discussed. The melting performances of cold-blast cupolas in practice are given. The shape of the C-lines on the diagram are considered with a view to optimum output and melting loss. The effect of coke size and quality and of the size of charge and the nature of the iron used on the melting process is described. The reactions taking place are described. Finally the deterioration of the lining and the effect of climate on the melting are discussed.—R. J. W.

The Improvement in Properties of Molten Iron. IV. Utilisation of Oxygen Blowing for Cupola Molten Iron. T. Tottori. (*Tetsu to Hagane*, 1956, **42**, Mar., 230–231). [In Japanese]. Particulars are given of higher temperatures reached and improved chemical and structural properties of the iron.

The Problems of Melting Cast Iron in the Induction Furnace. B. Marinček. (*Giesserei*, 1956, **43**, Aug. 30, 527–536). The requirements to be met by an induction melting plant in the foundry are enumerated. Medium and low frequency furnaces are described and compared. This type of furnace is admirably suited to soaking the melt at temperature. Current consumption under different conditions and different types of

furnace lining are discussed. Finally the economic efficiency of the induction furnace is compared with the cupola. 15-ton crucibles with a throughput of 4 tons/h have been found economic.—R. J. W.

Medium Frequency Induction Heating in Melting Practice. F. Hengelhaupt. (*Giessereitechn.*, 1956, **2**, Sept., 193–198). A few typical melting installations are described. Characteristics of medium frequency heating methods are discussed. A new series of coreless induction furnaces up to 500 kg recently developed in the East German Republic is illustrated and its method of operation is described.—L. J. L.

Experiences in the Operation of Low Frequency Coreless Induction Furnaces for Melting Magnesium, Aluminium and Cast Iron. G. Serwe and W. Zschintzsch. (*Giesserei*, 1956, **43**, Aug. 30, 537–539). Melting plants for magnesium, aluminium, and cast iron using low-frequency coreless induction furnaces are described separately. Operating experience including efficiency and economic aspects of these plants are also discussed.—R. J. W.

Characteristics of a Cast Iron with 24% Aluminium. E. Hugony. (*Fonderia Ital.*, 1956, **5**, Aug., 286–290). [In Italian]. The author examines the effects of adding Al and Fe. Briefly these are to increase resistance to oxidation at high temperatures, to increase resistance to nitric acid, and to give the iron special magnetic characteristics. Details are given of experiments carried out on test pieces containing 24% Al. The Fe–Al diagram is reproduced as well as the diagram of graphitic carbon, total carbon and aluminium content. Micrographs show the distribution of graphite in the iron. (10 references).—M. D. J. B.

The Effect of Mg on the Graphitization of White Cast Iron. K. Okabayashi and K. Futakawa. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Aug., 378–382). [In Japanese]. Experiments were made with added Cu–Mg alloy and pure magnesium. The graphitization time of white irons is shortened with small amounts of residual magnesium, because of its strong effect on deoxidation and desulphurization, but is prolonged with increasing amounts, because of retarding of graphitization. Graphitization of irons containing sulphur is particularly promoted by magnesium. With increasing amounts of residual magnesium, greater numbers of small, round temper carbon granules are found; also, in furnace-cooled graphitized specimens, areas of pearlite in the matrix increase.—K. E. J.

Thin Permanent-Mould Castings: Design and Production Problems. A. M. Petrichenko. .(*Iron Steel*, 1956, **29**, Oct., 473–477). Although certain properties of cast iron render it unsuitable for the production of thin-walled castings, its thermal properties and the low thermal stressing of the mould enable the difficulties to be surmounted. The author discusses some of the design and production problems, including the design of the casting and permanent-mould, the prevention of chilling, and the correct choice of casting system.—G. F.

Precision Casting by the 'Lost Wax' Process. R. G. Nicholas. (*J. Inst. Prod. Eng.*, 1956, **35**, Dec., 727–740). A comprehensive description of the lost wax process for precision casting is presented.—B. G. B.

Possibilities of Precision Casting. Metallurgical and Technological Aspects and Advantages. Y. Dechamps. (*Fonderia Ital.*, 1956, **5**, May, 183–194). [In Italian]. After a brief review of the principles of lost wax precision casting techniques, the author discusses the present possibilities of the method, the precautions to be taken at the project and design stages, the practical means of preparing the wax models, the metals which can be used, and finally the advantages of the lost wax process compared with other methods.—M. D. J. B.

Study of Properties of Shell-Cast Grey Iron Tensile Test Bars. T. Tanaka and T. Watanabe. (*J. Mech. Lab.*, 1956, **2**, 39–40). Curing time and temperature, resin concentration, cooling rates and back-up materials were studied.

Investigation of the Cooling of Large Castings Cast in Sand Moulds. J. P. Jegorenkow. (*Giessereitechn.*, 1956, **2**, Sept., 206–209). The results are reported of temperature measurements using automatic potentiometers and Cr–Al thermocouples on five castings for machine tools. The cooling period of castings has been divided into five stages. It is concluded that an extended residence time of the casting in the mould will not prevent the formation of internal stresses; knocking out at high temperatures and steady cooling in controlled conditions are advocated.—L. J. L.

On the Testing of Shrinkage Cavities in Cast Iron. A. Wittmoser, H. A. Krall, and L. Hütter. (*Giesserei*, 1956, **43**, Aug. 2, 409–418). A comprehensive article on shrinkage cavities in cast iron (36 references). The base for their formation (fluid contraction, solidification contraction, and solid contraction) are discussed in detail. Consideration is given to the amount of graphite separating from the eutectic. The design of an optimum experiment and of the proposed experimental moulds are discussed. Several experiments with different moulds are described. Finally the theoretical and practical position of shrinkage cavity formation is reviewed.

Fettling and Cleaning Methods and Equipment. F. Gaiger and R. Hancox. (*Found. Trade J.*, 1956, **101**, Oct. 18, 437–444). A detailed description is given of the changes recently carried out in the grey iron and Meehanite dressing shops of John Harper and Co., Ltd., Willenhall. Particular attention is paid to the development of incentive schemes, and to the effects of the changes on personnel, productivity, and costs.

Dust Problems in Foundries. K. Guthmann. (*Giesserei*, 1956, **43**, Aug. 30, 572–579). Legal and official prescriptions for the prevention of air pollution in different countries are first given. Air contamination in large cities is then considered from various sources in industry, the domestic use of coal, small consumers, and from transport. Data collected on the deposition of dust originating from metallurgical plants are quoted. Finally, the possibility of eliminating dust formation in cupolas is discussed.—R. J. W.

Safeguards for the Prevention of Accidents in the Die-casting Foundry. G. Lieby. (*Giesserei*, 1956, **43**, Aug. 30, 548–557). Safeguards against the premature release of shots from the die-casting machine are described, together with safeguards against unintentional movements of the die holding press. Precautions which should be taken in the danger zone of the die-casting machine are given. Similarly, measures to prevent accidents on melting and soaking furnaces are suggested.

The Physical Strain of Work on Man in the Foundry. G. Lehmann. (*Giesserei*, 1956, **43**, Aug. 30, 520–527). Industrial physiological methods for the quantitative determination of the strain of work and for the permissive turnover of calories in man are first described. The strain caused by heat and noise and by the various processes in the foundry are described. Examples are given in which a decrease in the strain and an increase in production are effected by mechanization and the use of modern equipment.—R. J. W.

VACUUM METALLURGY

Vacuum Problems in Metallurgy. K. Diels. (*Berg-Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 201–207). It is stated that vacua lessen the chemical effects of gases, reduce the mean free path of molecules, disturb the adhesion of gases to surfaces and lower boiling points. These effects are considered in relation to degassing of liquid steel, degassing during annealing, sintered metal production, melting, alloying distillation and sublimation of metals, and vacuum evaporation for production of metallic films on metals and non-metals. Available equipment for these processes is described.

Position of Vacuum Techniques. R. Jaeckel. (*Berg-Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 193–201). Vacuum ranges are defined under the categories coarse, fine, high, and ultra-high. Details and illustrations of various centrifugal and rotary pumps, air and steam aspirators, mercury diffusion pumps, and instruments for measuring these ranges of vacuum are given.

High-Vacuum Melting. E. Schwarz-Bergkampf. (*Berg-Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 248–250). This surveys the suitability of materials, particularly cast iron, steel, ceramics, and glasses for the construction of vacuum melting equipment. Materials and methods used for making vacuum-tight joints are discussed.

The Development of High-Vacuum Induction Melting Furnaces. O. Winkler. (*Berg- Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 207–214). Commercial induction vacuum melting furnaces are described and future developments are discussed. The cost of a one-ton vacuum melting installation is outlined.

Constant Vacuum Unit Tightens Melting Schedules. (*Iron Age*, 1956, **178**, Sept. 13, 98–99). A new vacuum melting and pouring plant for high temperature alloys at Allegheny-Ludlum Steel Corp. is described; at present a test unit melting 300 lb metal, it is designed for producing 2000 lb ingots. 3 vacuum locks allow a continuous vacuum of under 10 microns to be maintained.—D. L. C. P.

The Basis and Limits of Vacuum Melting Techniques. W. Deisinger. (*Berg- Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 214–219). Vacuum melting is discussed with regard to achieving still greater degassing, the avoidance of oxidation and particularly selective oxidation of alloys of metals of different oxygen affinities, the possibility of using less or no deoxidant and so avoiding the undesirable effects of same, and preferential evaporation of constituents of the melt according to vapour-pressure. Design features of Vakuumschmelze A.G.'s vacuum induction melting and pouring units are described, including one of 600 Kg capacity.

The Vacuum Annealing of Steel Strip. O. Felgel-Farnholz, H. Sidan, and W. H. Scheibe. (*Berg- Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 250–257). Vacuum annealing of strip is compared with protective atmosphere annealing. A vacuum of 10^{-1} mm of mercury is stated to be generally sufficient. The method has the advantage that decarburization and scaling are eliminated. Although containers for vacuum annealing cost more than those for protective gas annealing, the provision of the vacuum costs less than the supply of protective gases. Vacuum annealing is especially advantageous for thin strip required to undergo cold working, stainless chrome steels, and other steels requiring a high finish.

Further Development of the Vacuum-Hot-Extraction Method of Analysis. H. Feichtinger. (*Berg- Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 230–238). The following improved features of a vacuum-hot-extraction method are described: rapid collecting pump, micro-gas analyser, and interchangeable unit construction. Accuracy is obtained with both low and high gas content material, samples of 10 to 20 g and 2 to 4 g respectively being used. Other special features are a simplified arrangement of gas collecting pump, automatic control of water cooling for certain parts, rapidly interchangeable glass connection between furnace and diffusion pump, turnable tilting diffusion pump to enable the furnace to be sealed off quickly, and an arrangement for introducing samples without breaking vacuum. An oxygen determination can be done in 8 minutes.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Selection of Heat Treating Process and Equipment. E. J. Pavesic and R. T. Sinnott. (*Metal Progress*, 1956, **70**, Oct., 83–85). Factors which must be considered in deciding between batch and continuous heat treating equipment are discussed.

Efficient Tank Heating. A. E. Tyrrell. (*Metal Ind.*, 1956, **89**, Dec. 14, 495–496). **Furnace Efficiency.** (Dec. 21, 517–518). An account of a paper on gas heating presented to the Institute of Fuel. Design and operation of heat-treatment furnaces are reviewed.

Propane and Butane Gas for Generating Controlled Atmospheres. S. Yamada. (*Tetsu to Hagane*, 1956, **42**, Mar., 340–342). [In Japanese]. The constituents of converted propane and butane gases (N_2, H_2, CO_2, CH_4) are plotted for a temperature of 900° C for burning the hydrocarbons with air: hydrocarbon ratios varying between 5 and 21.—K. E. J.

Experiments with Sulphite Cellulose Waste Liquor as a Quenching Medium for Steel Heat-Treatment. R. Mitsche and E. Bierbrauer. (*Berg. Hüttenmänn. Monatsh.*, 1956, **101**, July, 12–18). Experiments on steels, especially constructional steels, are described showing that the waste liquor known as "Montanol" is suitable as a quenching agent.

Ultrasonic Quenching: It's New, More Effective. T. J. Bulat. (*Iron Age*, 1956, **178**, Aug. 30, 83–85). The method and advantages of "ultrasonic quenching" are described. Ultrasonics applied to quenching media cause vibratory waves which break down the vapour phase adjacent to the work. In addition to speedier cooling the following advantages are reported: higher work hardness, less distortion, less oil drag-out, less scale, cheaper quenching oil possible. Tests are reported in illustration, but the method could be applied to production parts.—D. L. C. P.

Hot-bath Quenching at Low Temperature Range of High-C, Low-Cr, Low-W Steel. I. Tatsukawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 249–251). [In Japanese]. The effect is studied from results of isothermal expansion tests for times up to 24 hours, and differential expansion and magnetic analysis results on tempering after hot-bath quenching (at 180° or 150° C) and oil-bath quenching.—K. E. J.

The Dimensional Stability of Ball Bearing Steel. I. (*Tetsu to Hagane*, 1956, **42**, July, 556–561). [In Japanese]. Arrested quenching at high temperature produces marked dimensional changes in room-temperature ageing, the greater part of which occur within 1½ days after quenching. Rapid cooling in cold water reduces the changes. Tempering after arrested quenching gives the greatest dimensional changes. High temperature of quenching oil does not improve dimensional stability, but the temperature has no effect in the case of arrested quench. Increased tempering time and secondary tempering improve dimensional stability, as does repeated quenching.—K. E. J.

Study on the Hardening of Cast Iron. III. Relation between Strain and Residual Stress in Cast Iron Treated by Quenching. K. Okabayashi and Y. Sunahara. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, July, 322–325). [In Japanese]. Relationships between quenching strain and cracks and the internal stress from quenching are discussed. Tests were made on specimens having flaky and nodular graphite structures, and on 0·5% C steel. Strain and residual stress in those treated by normal quenching were larger than in induction-heated specimens. With the flaky graphite specimen, the relative difference between compressive stress on a tangential direction near the surface and that of the inner diameter was smaller than with the other two.—K. E. J.

Carbides of Iron and their Behaviour in Tempered Steel. S. Oketani. (*Tetsu to Hagane*, 1956, **42**, Aug., 674–684). [In Japanese]. A review is made of published work on formation and decomposition of carbides and their composition. The tempering of quenched steel is investigated by a specific heat method, and a tentative mechanism is proposed. (18 references).—K. E. J.

FORGING, STAMPING, DRAWING, AND PRESSING

Recent Trends in Drop-forging Plant. J. H. Callaghan. (*Metal Treatment*, 1956, **23**, Nov., 446–450). The author, basing this article on his observations at a German convention, describes and compares the different types of hammers and presses, and discusses present tendencies in design.

Reconditioning Steam-hammer Forging Dies. (*Steel Processing*, 1956, **42**, Nov., 619–620). Briefly describes the grinding procedure used to remove up to ⅜in. of metal from Ni–Cr–Mo steel dies. This has replaced the use of machinery on a special planer set-up.—A. H. M.

Tungsten Carbide Dies. (*Steel Processing*, 1956, **42**, Nov., 629–630). Examples of the use of tungsten carbide dies in stamping silicon steel are given. Advantages claimed are: elimination of edge grinding, fewer rejects, increased efficiency, and long production runs.—A. H. M.

Automation in the Drop Forging Industry. H. M. H. Fox. (*J. Inst. Prod. Eng.*, 1956, **35**, Dec., 747–750). A short account of automatic equipment now in use in drop forging, heating, and heat-treatment is presented.—B. G. B.

Bending by Rolling of Ferrous and Non-ferrous Plate and Sheet. (*Sheet Metal Ind.*, 1956, **33**, Nov., 813–817; Dec., 887–894, 895). The requirements of roller bending machines are discussed and a comparison is made between vertical and horizontal machines. A survey is given of a wide range of machines, their best application, and the mode of operation.

On Deep-drawability and Anisotropy of Mild Steel Sheets. Y. Hosoi. (*Tetsu to Hagane*, 1956, **42**, Mar., 346–347). [In Japanese]. Discs were taken from plates of Armco iron (1·00 mm thick) and killed and rimmed steels (0·80 mm thick); the drawing reductions were 50·4% and 46·3%. Erichsen test results are given for these without heat treatment, and as annealed for 20 min at 650, 820, and 950° C. The ratio torque/volume shows a cyclic variation against the angle from the rolling direction; the cycle is complete after 90° for no heat treatment, but after 180° for an annealed specimen.

Deep-drawing Properties of Steel Sheet. II. Strain-ageing and Deep-drawing Properties of Al-killed Steel. T. Fujii. (*Tetsu to Hagane*, 1956, **42**, Mar., 348–350). [In Japanese]. Results of tensile, hardness, and Erichsen tests are given for a rimmed steel, an aluminium-killed steel, and steels with additions of 0·05% and 0·08% V, in three conditions: after skin-pass, and the same with heat-treatment for 3 min at 100° C and 200° C.—K. E. J.

Flange Wrinkling in Deep-Drawing Operations. B. W. Senior. (*J. Mech. Phys. Solids*, 1956, **4**, Aug., 235–246).

A method of predicting conditions of stability and number of waves formed is given.

Tubes as Raw Material. Complex Shapes by Precision Cold Drawing. (*Engineering*, 1957, **183**, Jan. 18, 86–87).

Metallic Blasting Media and Their Testing. E. Bickel. (*Stahl u. Eisen*, 1956, **76**, Aug. 23, 1116–1129). Various types and qualities of blasting media for the treatment of metal surfaces are considered, and their evaluation is discussed.

On the Shot for Peening. III. Effect of Shot Hardness on the Residual Stress. M. Uchiyama and K. Kamishohara. (*Tetsu to Hagane*, 1956, **42**, July, 569–573). [In Japanese]. Residual stress is greatest at the surface when soft specimens are peened with hard shot; otherwise it is greatest within the specimen. The maximum stress is found when the hardnesses of shot and specimen are equal, and this should be the case in practice. The size and velocity of shot have only minor effects on residual stress. The depth of the cold-worked layer increases with difference in hardness between specimen and shot.—K. E. J.

Crucible Steel's Stainless Steel Fine Wire Mill. E. D. Sickels. (*Wire and Wire Prod.*, 1956, **31**, 314–316, 350–351). The plant described is that of the Sanderson-Halcomb Works, Syracuse, N.Y., laid out to give a straight-line flow of material from rod to shipping department. The entire mill is housed in one building and comprises process bright annealing in strand form with in-line coating for further drawing. Reference is also made to the heavy wire mill.—J. G. W.

A Wire Mill in a Barracks. (*Wire Ind.*, 1956, **23**, Jan., 61–62, 85). An account of Stainless Steel Wire Co., Sheffield.

Steel Wire: Some Recent Developments in Europe. R. S. Brown. (*Wire and Wire Products*, 1956, **31**, Nov., 1328–1330, 1388). A general review of drawing and dies, descaling and pickling, patenting and galvanizing.

Rylands Celebrate 150 Years of Wire Manufacture. (*Wire Ind.*, 1955, **22**, Nov., 1062–1063).

Cold Rolling and Drawing of High-Strength Cable Wire Section. H. Krautmacher. (*Stahl u. Eisen*, 1956, **76**, Aug. 23, 1085–1099). The reasons for the investigation are given and the literature of the subject is reviewed. Preliminary tests were carried out on steel wires of various carbon contents. The main tests consisted in the drawing of two different sections, and the cold rolling of Z-section in three experimental series. The apparatus used for the tests is described and the results are given and discussed.

Stainless Steel Wire Drawing through Diamond Dies. W. F. G. Kerley. (*Wire and Wire Prod.*, 1956, **31**, June, 664–670, 711–712). Machines, dies, plant, and drawing practice for fine austenitic, low carbon, stainless steel wire, with reference to the fine wire mill of Samuel Fox and Co., Sheffield. The main stress is on the manufacture and maintenance of diamond dies. Reference is made to die performance and to lubrication.—J. G. W.

Electromatic Oil Tempered Wire. G. A. Sweitzer. (*Wire and Wire Products*, 1956, **31**, Oct., 1155–1159, 1278). High-carbon spring steel wire is described and properties and structures are shown.

Metallurgical Aspects of Scale Control on Hot Rolled Rods. E. L. Knapp. (*Wire and Wire Products*, 1956, **31**, Aug., 873–877). Methods of minimizing scale formation are mentioned and the effects on wire quality noted.

Electro-erosion. Its Application to Wire Drawing Dies. (*Wire Prod.*, 1956, **5**, Nov., 5, 7, 9, 11, 13).

Wire-drawing Lubricants. F. Rabenhorst. (*Wire and Wire Prod.*, 1956, **31**, Feb., 196, 238). The principal types of lubricant in powder, paste, and fluid form, are briefly indicated.—J. G. W.

Lubrication in Steel Wire Drawing. W. Lueg and K.-H. Treptow. (*Stahl u. Eisen*, 1956, **76**, Aug. 23, 1107–1116). The experimental materials and methods are described, with a reference to the draw-force meter. The results are given and discussed.

Lubrication in Wire-drawing of Steel, Nickel Chromium Alloys, Tungsten and Molybdenum. (*Wire Ind.*, 1956, **23**, Mar., 223–224, 242). A brief review, reprinted from a booklet.

Colloidal Graphite as a Wire-drawing Lubricant. D. G. Weaver. (*Wire and Wire Prod.*, 1956, **31**, Feb., 184–185, 229–232). Examples of the beneficial role of colloidal graphite in wire-drawing lubrication are quoted, including hot drawing and wet drawing of copper coated steel wire.—J. G. W.

Wire-drawing Lubrication. Where Do We Go From Here ? R. Tourret. (*Wire Ind.*, 1956, **23**, Jan., 41–44, 56). Lubrication theory, soaps and extreme pressure types, die profiles and lubrication systems are considered.

Plastic Flow in a Converging Conical Channel. R. T. Shield. (*Wire Prod.*, 1956, **5**, July, 7–11, 13). A theory is given and applied to wire-drawing.

Wire Flattening Theory. R. D. Weber. (*Wire Ind.*, 1956, **23**, Sept., 811–814, 816, 837).

Wire Flattening Practice. R. D. Weber. (*Wire Ind.*, 1956, **23**, Nov., 1007, 1009–1012, 1030).

A New Apparatus for the Precise Measurement of the Diameter of Fine Wire. I. G. Morgan. (*Wire Ind.*, 1955, **22**, Nov., 1057–1058).

Electronic Measurement of Hot Rolled Wire Rod. C. D. Gibbs. (*Wire and Wire Prod.*, 1956, **31**, Jan., 72–74, 77). The development of an optical gauge for measuring the size and shape of rod emerging from the finishing stand of a rod mill is reported. It is based on the design of the hot-strip width meter of the Industrial Gauges Corp., Englewood, N.J. Preliminary mill trials have established its suitability for use as a tool in mill control.—J. G. W.

Isotope Tracer Methods Developed in Great Britain. (*Wire and Wire Products*, 1956, **31**, Nov., 1337–1342). Methods of investigation of die wear are described and results presented.

An Approach to the Organisation of Maintenance in the Wire Industry. J. T. May. (*Wire Ind.*, 1955, **22**, Nov., 1069–1072, 1075).

Extrusion of Metals. P. Feltham. (*Metal Treatment*, 1956, **23**, Nov., 440–444). A theory of the criteria and efficiency of the extrusion process for metals is developed. Relations between extrusion force, ram velocity, friction at the billet container interface, and high-temperature rheological properties of metals are established and used to evaluate extrusion pressures for aluminium, copper, and lead.—A. H. H.

Studies on Cold Extrusion of Steel. I. Experimental Results of Cold Backward Extrusion in 100-ton Amsler Testing Machine. F. Kodama. (*Tetsu to Hagane*, 1956, **42**, Mar., 343–345). [In Japanese]. For seven steels (compositions given) the extrusion power is plotted in terms of the length of extrusion path. Similar curves are plotted for various conditions of the steels, viz. as-rolled, normalized, annealed, and spheroidized to different degrees.—K. E. J.

Studies on Cold Extrusion of Steel. II. Experimental Results of Cold Forward Extrusion in 500-ton Hydraulic Press. F. Kodama. (*Tetsu to Hagane*, 1956, **42**, Mar., 345–346). [In Japanese]. Data are given for the extrusion power and surface temperatures at selected portions of the surface for 20, 40, and 60% degrees of fabrication of a steel of given composition.—K. E. J.

Study on the Tool for Steel Tube Making. E. Miyoshi. (*Tetsu to Hagane*, 1956, **42**, Mar., 188–191). [In Japanese]. Results are given of calculations of the effects of thermal conductivity and the temperature change with piercing time in the plug. Results are also given of a series of comparative tests with plugs cast in sand moulds, cast in metal moulds, used several times, heat-treated at various temperatures, and having forged heads.—K. E. J.

ROLLING-MILL PRACTICE

Contribution to the Study of Rolling Mills. G. Grenier. (*Echo Mines*, 1956, Oct., 589–592; Nov., 654–655). Part I of a series of articles. General design is briefly considered and the mechanism of hot rolling is taken up. Deformation, limits of ductility, conditions for nip and for continuation of reduction are then given.

Problems of Metallurgy. Academy of Sciences of the U.S.S.R. Moscow, 1953. **Present-Day Problems in Rolling.** I. M. Pavlov. (317–326). [In Russian]. Some of the problems of rolling-mill practice whose solution is most urgently required for the realization of planned production increases in the U.S.S.R. are outlined, with indications of possible solutions. **Characteristics of Final Deformations.** V. G. Osipov. (327–364). Various parameters used for characterizing deformation are defined and their relationships discussed. Deformation curves in terms of different parameters are examined and the selection of optimal characteristics of deformation is considered. **Ways for the Further Development of Reducing and Section Rolling-Mills.** B. P. Bakhtinov and M. M. Shternov. (365–377). Various rolling-mill layouts, working methods, stand designs, and roll-pass designs are critically examined, and the past and future evolution of

rolling-mill practice discussed. **Some Rules Involved in the Rolling Process.** M. L. Zaroshchinskii. (378–391). The rules involved in the following are considered: direction of movement of the metal at the deformation centre, the relation of spread to parameters of the deformation centre, dependence of the absolute spread on strip width and the influence of the division of the deformation into steps on spread. **Influence of Outer Zones on Widening and Distribution of Speeds and Stresses across the Width of a Strip during Rolling.** A. I. Tselikov. (392–406). The differences in speed and stress at various transverse points in a strip being rolled are examined, first neglecting the influence of outer zones and then allowing for this. Results obtained are considered to invalidate several widely used treatments of deformation during rolling.—S. K.

Power Requirements and Selection of Electrical Equipment for Reversing Cold Strip Mills. J. E. Peebles. (*Iron Steel Eng.*, 1956, **33**, Dec., 102–120). A comprehensive review of requirements and installations.

The Load on a Three-High Finishing Stand and on its Drive in Rolling Sheet, Bars and Billets. W. Lueg and H. G. Müller. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1457–1463). Recordings free from inertia of the loads acting on the stand and of the torque of its electric drive show impact-like loads and short-time vibrations. Roll force is not equally distributed between the two rolls. This is attributed to uneven roll diameters, uneven heating of the bars and billets to be worked as well as varying scale thickness on their surfaces. In some cases it was found that one of the work rolls actually ran as a drag roll or that a negative momentum resulted from the rigid clutch of the pinion drive.—T. G.

The Load Distribution in Billet Trains. W. Lueg and H. G. Müller. (*Stahl u. Eisen*, 1956, **76**, Nov. 15, 1562–1564). Torque measurement on two stands of a six-stand tandem billet train showed uneven load distribution to the individual stands. These are attributed to tensile and compression stresses in the billets which affect the torques of several stands.

Calculation of the Rolling Pressure of Plane Metallic Shapes, and Theories About the Same. A. Truan. (*Dyna*, 1954, **29**, Dec., 561–582; 1955, **30**, Jan., 19–48; June, 389–406; July, 455–469). A review.

A Proposed Method for Calculating Residual Stresses in Iron Rolls. C. F. Peck, jun. (*Iron Steel Eng.*, 1956, **33**, Dec., 121–124). Surface stresses are measured and internal stresses calculated from these on certain assumptions. Data from 4 rolls are used and may not be typical.

Manufacture of Chilled Cast-Iron Rolls by Electric Furnace Melting. C. Passeggio. (*Bol. Assoc. Brasil. Met.*, 1956, **12**, Apr., 125–133). [In Portuguese]. An account is given of the roll making method at the Aco Villares Foundry (Brazil). Two direct arc furnaces and one H.F. furnace are used independently, or together for larger rolls, with satisfactory results. 40 to 60% roll scrap, 35 to 50% pig iron with a balance of steel scrap is charged and melted down with maximum voltage, pieces of coke being used to reduce the degree of oxidation. Low temperature working was found to cause a large grain size region between the chill layer and the core of the roll so medium temperature working was adopted followed by cooling to the tapping temperature. The optimum FeO content in the slag is found to be between 1·7 and 2·0%. The greatest difficulty encountered is the variable quality of the pig-iron available.—P. S.

Problems of Cast Alloy Steel Rolls and Some Other Alloy Steel Products. N. Yamamoto. (*Tetsu to Hagane*, 1956, **42**, July, 595–602). [In Japanese]. Recently-established techniques are described for the production of cast alloy steel rolls, built-up and back-up rolls, main steam pipes for high-temperature high-pressure boilers, and gas-turbine parts.

Electron Microstructure of the Working Roll for Cold Rolling. III. K. Gokan. (*Tetsu to Hagane*, 1956, **42**, Mar., 306–307). [In Japanese]. Electron micrographs are compared for the quenched and two tempered (for 20 and 40 min after quenching) states.—K. E. J.

Tapered Roller Bearings. (*Iron Steel*, 1956, **29**, Dec., 546). A brief outline is given of the manufacture of heavy-duty roller bearings at the Daventry works of British Timken Ltd., and some of their applications are indicated.—G. F.

Higher Rolling Mill Output Stirs Inquiry Into Ingot Thickness. (*J. Met.*, 1956, **8**, Nov., 1541). A brief outline is given of the problem of ensuring uniform quality in large rimming ingots, now even more necessary due to the increased use of high-speed, high-capacity continuous rolling techniques.—G. F.

Rolling Mills of [Osaka Steel Mfg. Co., Ltd.] Y. Takaishi (*Tetsu to Hagane*, 1956, **42**, July, 591–595). [In Japanese]. Details are given of a small semi-continuous mill for small round and other bars at Amagasaki; a mill for small-section bars and wire rod at Kyobashi; and a continuous medium-size mill at Kyobashi, having a monthly capacity of 15,000 tons.

Friction in Cold Rolling. G. T. van Rooyen and W. A. Backofen. (*J. Iron Steel Inst.*, 1957, **186**, June, 235–244). [This issue].

A.S. & W. Places New Rod Mill in Operation at its Cuyahoga Works. (*Wire and Wire Prod.*, 1956, **31**, July, 765–766, 810–811). The new rod mill installed at the Cuyahoga Works of the American Steel and Wire Division of the United States Steel Corporation, is described and illustrated. Designed for an annual capacity of 450,000 tons by A.S.W. together with the Morgan Construction Co., the mill consists of 25 stands and rolls four strands from 1200 lb wt, 3¼ in. × 3¼ in. billets to sizes ranging from No. 5 gauge rod to 1½ in. diameter, the range $\frac{9}{16}$ in.–1½ in. diameter being rolled in either double or single strand.—J. G. W.

Hot-Rolled Special Sections Carry Built-In Savings. W. H. Mohr. (*Iron Age*, 1956, **178**, Nov. 1, 91–94). The desirability of employing specially rolled sections is considered, and examples of their use given.—D. L. C. P.

Velindre Cold Mill: Details of B.T.H. Electrical Equipment. (*Iron Steel*, 1956, **29**, Dec., 559–560). A description is given of the main drives and control equipment supplied by British Thomson-Houston Co., Ltd. for the new Velindre 5-stand tandem cold strip mill of Steel Co. of Wales Ltd.—G. F.

Electrical Equipment for a High-Speed Tandem Cold Strip Mill. (*Metallurgia*, 1956, **54**, Dec., 283–286). The electrical equipment for a new 5-stand tandem cold reduction mill at the Velindre works of the Steel Co. of Wales constructed by the British Thomson-Houston Co. is described. The mill will roll steel strip to tinplate gauges at speeds of up to 5000 f.p.m.

The Rolling Mills at the Port Talbot Plant of the Steel Company of Wales Ltd. H. H. Ascough. (*Blast Furn. Steel Plant*, 1956, **44**, Sept., 1033–1039; Oct., 1168–1174; Nov., 1296–1301, 1304). A comprehensive description of the design and operating practice at the Abbey Works, Steel Co. of Wales is given. The mills are designed to produce hot and cold rolled sheets, hot rolled strip for cold rolling to tinplate, black sheets and plates. An ingot make of 1,800,000 tons has been achieved from the initial stage of development. A second development stage is nearing completion to provide an annual ingot make of 2,500,000 tons. A third stage has recently been sanctioned increasing the ingot make to 3,000,000 tons/annum. Under this latter stage the present 45-in. slabbing mill is to be converted to a universal mill to ensure 60,000 tons/week. Full details of the hot and cold mills are given.—B. G. B.

Old Rolling Mills Yield More Tonnage, Better Strip. T. J. Connell. (*Iron Age*, 1956, **178**, Oct. 4, 104–106). The handling facilities installed to improve the production of a 30 year-old mill are described.—D. L. C. P.

On the Experimental Cold Strip Mill (I). K. Nakamura and H. Takahashi. (*J. Mech. Lab.*, 1956, **2**, 41–43). The mill is briefly described and diagrams are shown.

Cold-Rolling Process for Steel Strip. J. Martinez Gonzalez and R. Urcelay Azpitarte. (*Anal. Mec. Elect.*, 1956, **33**, Sept.-Oct., 236–245). [In Spanish]. An explanation of rolling theory for cold rolling is given and the Siebel and Orowan methods for the calculation of friction, power requirements, etc. are illustrated with numerical examples.—P. S.

The Detection of Rolling Defects in Steel Sheet. A. M. Armour. (*Metallurgia*, 1956, **54**, Dec., 301–304). Methods involving ultrasonic, mechanical, electrical or magnetic processes are all effective in detecting concealed defects in steel sheet if inspection time is not limited. Suggestions are made for improving the speed of the magnetic method.

Cause and Prevention of Hot Strip Work Roll Banding. C. E. Peterson. (*Iron Steel Eng.*, 1956, **33**, Dec., 98–101). Removal of scale, choice of hard, graphite-free roll material and water cooling are found to prevent banding.

A Width Meter for Hot Steel Strip. C. Burns and B. O. Smith. (*J. Iron Steel Inst.*, 1957, **186**, June, 218–223). [This issue].

Extensiometer for Skin-pass Mills. A. Abe. (*Tetsu to Hagane*, 1956, **42**, Mar., 342–343). [In Japanese]. An instrument is described for measuring reductions continuously; its results show an excellent correlation with those from measurements of gauge length.—K. E. J.

LUBRICATION

Does Specification Buying Save on Tool Lubricants. J. A. Boyd. (*Iron Age*, 1956, **178**, Sept. 6, 102–103). Factors to consider in specifying high performance cutting oils are considered. The chemical state of sulphur, chlorine and fatty oils may be important. Establishment of performance specifications is recommended.—D. L. C. P.

Some Experiments in the Lubrication of Stainless Steels. G. D. Jordan. (*Sci. Lubrication*, 1956, **8**, Aug., 14–19; Sept., 13–16, 18). Wetting tests were made with five oils on three types of stainless steel. The greatest wetting was found with an oleine-compounded oil on austenitic stainless steel. For austenitic, martensitic and ferritic steels, the best oils were oleine-compounded, pure paraffinic, and chloro-sulphurized, respectively. The results confirm the extensive use of oleine-compounded oils for cold rolling stainless steel.

Friction tests show that no one particular combination of stainless steel, bearing material and oil gives the best results from the aspects of temperature, friction and wear. Design and other factors enter into the choice of lubricant. There is no simple correlation between wetting and friction tests. Yellow metal appears to be a favourable bearing material to use with stainless steel, while the lubricating properties for cast iron or stainless steel, on stainless steel are very similar.

Pure Molybdenum Disulphide. H. P. Jost. (*Sheet Metal Ind.*, 1956, **33**, Oct., 679–690, 697). The author first deals with the occurrence, manufacture, and properties of MoS_2. Examples are then given of some applications of pure MoS_2; these include forming and drawing, press fits, running-in, conveyors, prevention of stick-slip, gears and threads, tapping of five threads, and a large number of miscellaneous applications.—A. H. M.

Friction of Possible Solid Lubricants With Various Crystal Structures. M. B. Peterson and R. L. Johnson. (*NACA TN* 3334, 1954, pp. 33; TIDU List 625). Salts of layer lattice types were tested on steel specimens. Ag I is not of this type but formed adherent films and was effective. Fe_3O_4, mica, talc and NiO were not adherent and did not protect the surface.

Friction Studies of Graphite and Mixtures of Graphite with Several Metallic Oxides and Salts at Temperatures to 1000° F. M. B. Peterson and R. L. Johnson. (*NACA TN* 3657, 1956, pp. 17; TIDU List 625). Steel and Inconel combinations were studied with graphite and its mixtures with lead and cadmium oxides, and sodium and cadmium sulphates.

WELDING AND FLAME CUTTING

Current Trends in Welding Steel Castings. W. H. Rice. (*Foundry*, 1956, **84**, Nov., 120–125). The factors to be considered in specifying a welding process for steel castings are summarized, and the application of a number of recent developments in welding practice to the repair of castings or to cast-weld fabrication are discussed. The processes covered are tungsten inert gas-shielded arc welding, metal inert gas-shielded arc welding, submerged arc welding, and metal arc welding with coated electrodes. The necessity for establishing programmes for experimental welding is briefly discussed.

Spotlight on Arc Welding. G. H. Coy (Engineers) Ltd. (*Welder*, 1956, **25**, July-Sept., 58–61).

Twin-Arc Welding for Hard Surfacing Scraper Blades. (*Metallurgia*, 1956, **54**, Dec., 312). The use of the twin-arc process with twin cored electrodes has reduced the time for hard surfacing scraper blades from 3 h to 1 h 48 min.—B. G. B.

Automatic Submerged-Arc Welding of Alloy Steel. R. A. Wilson. (*Metal Progress*, 1956, **70**, Oct., 104–107). Welds with properties which match those of the parent alloy steel can be made by the submerged-arc process with mild steel wire as the welding wire and special fluxes which supply the necessary alloying elements.—B. G. B.

Welding 5% Cr–0·5% Mo Steel Pipes with Austenitic Electrodes. Dr. H. G. Geerlings and W. P. Kerkhof. (*Lastechn.*, 1956, **22**, Nov., 176–181). [In Dutch]. This paper points out the advantages and disadvantages of using austenitic welding rods on 5% Cr–0·5% Mo steel pipes. The mechanical properties of the welds and the welding temperatures are looked into particularly as regards the transition point between the welded and welding materials. Results are shown of stress calculations regarding temperature changes taking into account the difference in the coefficient of linear expansion between austenitic and ferritic steels. They indicate that welds of the type under discussion may be adopted for working temperatures up to about 525° C.

Weld Stronger Joints In Low-Alloy Steels. R. D. Libert. (*Iron Age*, 1956, **178**, Oct. 18, 135–138). Applications of low-alloy-steel welded assemblies are described and welding methods explained. Advantages in cost and design are noted. Structures can have strength in excess of 200,000 p.s.i.

Welding Steel by the Inert-gas-shielded Metal-arc Process. A. R. Muir. (*Sheet Metal Ind.*, 1913, **33**, Sept., 599–605; 613–616). The process and some modifications and variations are described together with the arc and self-adjusting characteristics used. Welding conditions for stainless and mild steel are given, and the author finally discusses problems of cost and the advantages and limitations of the process.

Welded Fabrication and Weld Design. H. Albrecht, W. Lenk, and K. Trümner. (*Schweissen u. Schneiden*, 1956, **8**, Nov., 427–430). The influence of choice of material, equipment and time, and the most suitable weld design is discussed.—U. E.

Weld Complex Jobs Faster With Multipurpose Machine. (*Iron Age*, 1956, **178**, Sept. 13, 102–103). Use of a multi-purpose welding machine and modern electrodes for making the various welds required in assembling heavy strip-coil wagons is described.—D. L. C. P.

The Effects of Zinc Phosphate Coating on Flash Welding of Steel Tubing. J. F. Young and A. Phillips. (*Welding J.*, 1956, **35**, Sept., 416s–420s). The effect of surface zinc phosphate contamination is described on the strength and ductility of flash welds in steel tubing. The test results indicate that unless the residual phosphorus left from the tube drawing compound is removed prior to welding, brittle welds of low notch-bend strength may result.—U. E.

Calder Hall. Welded Fabrication in the Construction of Britain's First Atomic Power Station. (*Welding, Metal Fab.*, 1956, **24**, Nov., 384–392). Welding as applied to the different units which make up the station is discussed, with illustrations.

Preheating and Postheating for Field Erection of Mild-Steel Pressure Vessels. L. J. McGeady. (*Welding J.*, 1956, **35**, Sept., 444s–446s). A survey is given of field and service experience with regard to pre-heating and post-heating of welded pressure vessels. U. E.

Fabrication of Heavy Steel Components by "Squirt Welding." (*Machinery*, 1956, **88**, May 18, 749–750). Hidden-arc manual Lincolnweld machines are described, as used by Nordberg Mfg. Co. Milwaukee.

Investigation of Welds on Superheater Tubes made from Ferritic Alloy Steels. S. Heiskanen and K. Tikkanen. (*Jernkontorets Ann.*, 1956, **140**, (8), 529–550). [In Swedish]. Welding tests were made on 3 grades of cold-rolled superheater tube material (1% Cr, 0·4% Mo; 5% Cr, 0·5% Mo; 13·5% Cr) atomic hydrogen and gas welding being employed. After welding, some of the samples were left un-annealed, whilst others were annealed by burner flame or in a furnace for various periods. They were then subjected to flattening and hardness tests, chemical analysis of weld metal and microscopical investigations. Results are presented and discussed and some recommendations are made.—G. G. K.

Carbon Migration in Welded Joints at Elevated Temperatures. R. J. Christoffel and R. M. Curran. (*Welding J.*, 1956, **35**, Sept., 457s–468s). An investigation is reported on carbon migration in welded joints of low- and high-alloy steels. It is shown that carbon migration does not have a serious effect on physical properties. A mathematical treatment of carbon migration phenomena is included.—U. E.

Safety in Installation and Use of Welding Equipment. B. F. Postman. (*Welding J.*, 1956, **35**, Oct., 1021–1025). Daily safety requirements and practices especially those overlooked by supervisors and ignored by operators are discussed.—U. E.

Application of Safe Welding Practices. L. J. Rose. (*Welding J.*, 1956, **35**, Oct., 1034–1038). Seven basic principles of an established safety programme are discussed. These are: top management support, operation through supervision, making every employee safety-minded, extending efforts beyond the plant, instructing each new employee, safety instructions for every job, and adequate safety personnel.—U. E.

Development of Welding Safe Practices in an Industrial Plant. R. L. Snyders. (*Welding J.*, 1956, **35**, Oct., 1030–1033). The author discusses the work carried out by a committee of welding engineers and supervisors dealing with safety measures in General Motors.—U. E.

Health Aspects of Welding. B. L. Vosburg and J. J. Ferry. (*Welding J.*, 1956, **35**, Oct., 1015–1020). Articles dealing with

potential dangers in various welding operations and with the standards that have been set up to minimize such dangers are reviewed. The low hydrogen coating and inert-gas metal arc are discussed with regard to potential dangers inherent in these processes.—U. E.

Large or Small Test Bars—or No Tests At All? E. C. Winkel. (*Dansk Tekn. Tidsskr.*, 1956, **80,** (7), 177–181; (8), 205–208). [In Danish]. Pointing out that problems of weldability hardly existed before the war, mainly because the plates were quite thin as opposed to present-day welding of 1½ in. plates or more, the author attempts to obtain a clear definition of weldability. He discusses similarities between the Charpy and Schnadt tests and points out the disadvantage of small test bars, that plate thickness is not taken into account. Details are given of results obtained with the Swedish NC test and these are compared with results of Charpy and Schnadt tests.—G. G. K.

Inspection of Large Site-built Pressure Vessels. E. Crossley. (*Welding Metal Fab.*, 1956, **24,** Nov., 393–397). The inspection of large welded fabrications such as tanks, vessels, and towers is discussed. An example is given of testing and inspecting the reactor vessels built on site at Calder Hall.—U. E.

A Weld Cracking Susceptibility Test for Sheet Materials. E. H. Kinelski, G. R. Peace. (*Welding J.*, 1956, **35,** Oct., 498s–500s). Discussion of a paper by J. S. Boudreau published in April, 1956, **35,** 164s–168s. Modifications of the test and its procedure are discussed.—U. E.

Ultrasonic Testing of Penetration in T Welds. G. A. Homes. (*Rev. Soudure*, 1955, **11,** (4), 204–213). [In French]. A description is given of ultrasonic techniques for the testing of welds. Details of the apparatus are given; methods of auscultation and the results which can be obtained are discussed.—M. D. J. B.

Impact Performance of Synthetically Reproduced Heat-Affected-Zone Microstructures in " T-1 " Steel. E. F. Nippes and C. R. Sibley. (*Welding J.*, 1956, **35,** Oct. 473s–480s). " T-1 " steel, a low-alloy quenched-and-tempered steel was subjected to heat-affected zone thermal cycles attending a weld made in ½ in. plate. The microstructures were evaluated by Charpy **V**-impact tests. It is shown that only slight loss in toughness occurs.—U. E.

Magnetometric Method of Inspection of Welds. A. S. Fal'kevich, F. I. Kislyuk, Yu. V. Usenko and V. M. Lubov. (*Svarochnoe Proizvodstvo*, 1955, (7), 10–12). A continuous method of inspection using a recording tape is described and its applications outlined. Its development is described and the final recording system shown, and the reproduction unit with a neon lamp in circuit which lights up for flaws of predetermined magnitude explained.

Mild Steel Weld-Metal Porosity. J. T. Ballass and R. D. Stout. (*Welding J.*, 1956, **35,** Sept., 409s–415s). A report of an investigation on porosity in mild steel welds made by the inert-gas-shielded metal arc process. It seems that porosity is due to the carbon monoxide reaction and is reduced by the use of electrodes leaving a sufficient deoxidizer content. The importance of penetration is pointed out.—U. E.

Formation of Hot Cracks in Butt Welds with Extension of Tabs. S. L. Mandel'berg and O. S. Zabarils. (*Avtom. Svarka*, 1954, **7,** (6), 29–32). Cracks formed at the points of junction of the tabs and welds are examined by bending or stretching after welding by various methods. Automatic welding is advocated with movement over the tabs by hand.

Induction Heating Facilitates Production Brazing. C. W. Holt. (*Machinery*, 1956, **89,** Nov. 2, 1015–1019). Heating rates, effect of clearances, choice and application of flux and fixture design are dealt with.

Oxidation-Resistant Brazing Alloys. G. H. Sistare, jun. and A. S. McDonald. (*Welding Res. Council Bull. Series*, 1956, No. 30, Sept.). Alloys of gold-nickel-chromium, and palladium-nickel base alloys with chromium and silicon were developed and used for joining stainless steel to Inconel at brazing temperatures 1900–1950° F. The alloys can be torch brazed using flux, or without flux in a protective atmosphere. The resulting joints resist oxidation at 1600° F service temperature. A note on graphite-brazing is included.—U. E.

Basic Characteristics of Some Heat-Resisting Brazing Filler Materials. W. H. Chang. (*Welding J.*, 1956, **35,** Sept., 431s–443s). Two nickel-chromium-boron, one nickel-chromium-silicon and one gold-nickel brazing filler materials have been investigated. The dependence of intergranular penetration on both base and filler materials has been demonstrated. Joint microstructures have been examined and the advantages and limitations of the filler materials are discussed.—U. E.

Development of Brazing Alloys for Joining Heat Resistant Alloys. F. M. Miller, H. S. Gonser and R. L. Peaslee. (*Welding Res. Council Bull Series*, 1956, No. 29, Aug.). Nickel base binary and ternary systems containing phosphorus, silicon, chromium, manganese, molybdenum, tungsten and iron were investigated. It is found that the Ni–P–Cr and Ni–P–Si alloys showed optimum properties. Phosphorus and manganese contributed most toward improving the flow and wetting properties while silicon and chromium improved the oxidation resistance and strength.—U. E.

Silver-Brazing Lap Joints in Stainless-Steel Tubing. G. H. Bohn. (*Welding J.*, 1956, **35,** Sept., 884–889). Experimental data are given for silver-brazed lap joints in stainless steel tubing (type 300). It is shown that if the lap is made properly with commercial mill tolerances three times the thickness of the tubing, the joint will be stronger than the tubing with internal pressure, tension stresses due to thermal expansion and dead load, or a combination of the two.—U. E.

Wettability of Steel with Pure Silver and Various Silver-Brazing Alloys. N. Bredzs. (*Welding J.*, 1956, **35,** Oct., 508s–520s). An investigation of oxygen diffusion through layers of molten silver with and without deoxidizing additions has been made. The mechanism of the formation of iron oxide layers and nucleation of CO bubbles on the steel-filler metal interface was investigated. It was found that incomplete protection against exposure to air considerably impairs wettability. Some metals added can decrease the rate of diffusion of oxygen through molten silver. While nickel and tin protect the molten silver almost completely. Copper, in small additions will accelerate the rate of diffusion of oxygen.—U. E.

Brittle Failure of ' Bronze ' Welds. G. E. Morton. (*Brit. C.I. Res. Assoc. J. Res. Dev.*, 1956, **6,** Oct., 403–408). The occurrence of a layer of a hard brittle constituent at the junction of the parent metal and the weld when ' bronze ' welding cast iron, i.e. using copper-zinc filler materials, is demonstrated. It is recommended that the silicon content of the filler rod should not exceed 0·1%, i.e. sufficient to deoxidise and assist fluidity in the weld metal.—B. G. B.

100 Hours Saved by Oxygen Cutting. C. G. Davis. (*Welding J.*, 1956, **35,** Oct., 1039). Precision oxygen cutting through 26 in. steel thickness is briefly described.—U. E.

Certain Physico-chemical Aspects of Oxygen Cutting. C. Decroly and G. Genin. (*Rev. Soudure*, 1955, **11,** (4), 214–225; 1956, **12,** (1), 50–70; (2), 130–138). [In French]. This paper describes work carried out at the University of Brussels under the auspices of I.R.S.I.A. and the Belgian Institute of Welding. The researches cover all aspects, physical and chemical, of oxygen cutting, methodology, the behaviour of samples under a variety of conditions and the means by which best results can be achieved, such as, e.g. the optimum velocity of gases. Considerable technical data are given in table form. (9 references).—M. D. J. B.

CLEANING AND PICKLING

Sodium Hydride Descaling Process. W. F. S. Taylor. (*Metal Treatment*, 1956, **23,** Nov., 465–468). The author lists the advantages of the process and describes the plant and its operation. Cost and bath concentration are discussed.

Steel Plate Pre-treatment Plant. (*Corrosion Prevention and Control*, 1957, **4,** Jan., 54). An account of the Rose Mount Iron Works pickling and painting shop.

" Mechanical Cleaning." G. F. Jones. (*Bradley's Magazine*, 1956, Autumn, 3–4). A review of blast cleaning given to the Porcelain Enamel Institute on the treatment of sheet iron with steel shot.

Cleaning by Ultrasonics. J. Lomas. (*Machinery Lloyd*, 1956, **28,** Dec. 8, 94–96). A brief review.

Rapid Test for Checking Pickling Rinse Waters. I. Geld. (*Wire and Wire Prod.*, 1956, **31,** Feb., 200, 236). A simple chemical test is described for establishing the condition of the rinsing bath in the pickling process. The test has been developed at the U.S. Naval Material Laboratory, Brooklyn, N.Y.—J. G. W.

The Pretreatment of Metal Surfaces. M. Lewis. (*Sheet Metal Ind.*, 1956, **33,** Sept., 639–646). The purposes and importance of cleaning procedure are discussed and various cleaning operations are described. Phosphating is described in some detail and the properties of phosphate coatings are listed. Reference is made to anodizing treatments.—A. H. M.

PROTECTIVE COATINGS

Plating Adhesion: Which Test Do You Buy? P. M. Unterweiser. (*Iron Age*, 1956, **178**, Oct. 18, 123–125). Types of test for measuring the adhesion of electro-plated coatings to the basis metal are considered, and their respective merits noted. Only bend tests are widely accepted; a method which can be used in mass production is required.—D. L. C. P.

The Electrode Process in Metal Deposition from Aqueous Solutions. E. Mattsson. (*Acta Polytechn.*, 1955, **4**, (12), pp. 56). A mathematical treatment of ion-exchange considering the energy barrier by superposition of two potential curves one for the solution and one for the metal. The mechanism is represented as a series of steps taken from the literature. The interface region is discussed and free energy calculated from the effect of temperature.

Automation in Electroplating. D. W. Taylor. (*Process Control Automation*, 1956, **3**, Nov., 388–394). An illustrated account of types of plant available with diagrams of the control principles. Barrel and rack methods are described with details of loading and unloading.

Finishing Processes at a Vehicle Equipment Works. (*Indust. Finishing*, 1956, **9**, Nov., 212–213). The Efco-Udylite automatic plating machine is mainly described.

Hard Chromium Plating of Press Tools. J. W. Oswald. (*Sheet Metal Ind.*, 1956, **33**, Oct., 691–697). The difference in technique between decorative and hard chromium procedure is emphasized and the properties of hard chromium plating are listed, viz. hardness and wear resistance, low coefficient of friction, and corrosion resistance. Properties of the tool steel are discussed and the thickness of deposit normally used is given. Comparison is made between the performance of plated and unplated tools for a wide range of applications.—A. H. M.

The Production of Acid-resistant Plated Steel Sheet. R. O'Donnel. (*Neue Hütte*, 1956, **1**, Sept., 469–475). A method of producing steel sheet plated on one side with Cr or Ni according to Polish Patent No. 35469 is described in detail.

Chrome Waste Treatment. M. K. Young. (*Metal Ind.*, 1957, **90**, Jan. 25, 67–68). A review of ion-exchange treatment.

Nickel and Nickel Alloy Deposits. H. C. Castell. (*Metal Ind.*, 1956, **89**, Dec. 28, 536–540). Uses, mechanical properties and effects of heat treatment are all tabulated and discussed. Bath changes and effects of pH, temperature, and chloride content are briefly mentioned and fatigue strength is considered. Chemical plating is included.

Chemical Nickel Plating. (*Usine Nouvelle*, 1956, **12**, Sept. 20, 37). A brief review.

Recent Developments in Cadmium, Copper, and Zinc Protective Electroplating. (*Corrosion Prevention and Control* 1957, **4**, Jan., 37–42, 64). A review of developments in plating with these metals and their alloys with tin. Recommended procedures and standard specifications are mentioned.

Hot Dip Galvanizing 1946–1956. Part 3. Properties of the Hot Dip Galvanized Product. M. L. Hughes. (*Product Finishing*, 1956, **9**, Oct., 61–67). A general literature survey of corrosion resistance, coating thickness and composition, corrosion by hot water and white rust formation, adhesion, accelerated tests and defects is given. (97 references).

Hot-Dip Galvanizing. G. Rossi Landi. (*Rivista Mecc.*, 1955, **6**, Feb. 26 25–28). [In Italian]. The author discusses the present and future scope of hot dip galvanizing, describes both modern and old installations and considers the dilemma which faces many galvanizing works, namely to modernize or close down.—M. D. J. B.

Galvanizing Productivity: Comments on a Recent Study. C. James. (*Product Finishing*, 1957, **10**, Jan., 68–78). A commentary on the report of A. G. Northcott on a visit to the U.S. is given with recommendations, and various statistical data on efficiency, incentive schemes, and outputs are presented.

Choosing the Right Zinc Finish. C. James. (*Product Finishing*, 1956, **9**, Nov., 73–75). A brief discussion of the properties of plating, dipping, and spraying, with pretreatment, for welded steel frameworks.

Anti-Corrosion Treatment of Zinc Coatings. N. A. Solov'ev. (*Zhur. Priklad. Khim.*, 1956, **29**, (7), 1062–1066). [In Russian]. Treatment of zinc coated surfaces in solutions of chromic, sulphuric, and hydrochloric acids increases by 8 to 10 times their resistance to corrosion due to the formation of an oxidized film. The oxidized layer is very thin and therefore the polished surface of the zinc coating retains its brightness after the treatment.—V. G.

The Galvanizing of Triple Twist Netting. C. Lepage. (*Wire Ind.*, 1956, **23**, July, 597).

Bright Galvanized Steel Wire. (*Wire Ind.*, 1955, **22**, Nov., 1075, 1101). A brief account of production, additives, etc.

High Speed Tinning Line has Unique Features. J. W. Brinks. (*Iron Steel Eng.*, 1956, **33**, Nov., 133). A short account of features of Weirton Steel Co. plant.

Electrolytic Deposition of Tin in the Manufacture of Tinplate. C. Frenkel. (*Met. Ital.*, 1956, **48**, Oct., 433–442). [In Italian]. This article describes the electrolytic tinning process. Much of the information contained is based on British and American practice.—M. D. J. B.

Alkaline Copper Plating. M. Mercadov. (*Metal Ind.*, 1957, **90**, Jan., 27–28). Optimum conditions for baths containing Rochelle salt are reviewed.

Coating Carbon Steels by Immersion in Baths of Molten Aluminium. M. Serra. (*Inst. Hierro Acero*, 1956, **9**, July-Sept., 897–907). [In Spanish]. A study has been made of the coatings formed on five plain carbon steels (0·09 to 0·62% C) by immersion in baths of molten aluminium or Al–4% Si with and without sodium additions. The presence of silicon in the bath caused a reduction in the thickness of the intermetallic layer, giving a smoother cross-section. In both types of bath, the addition of sodium gave better wetting properties and thus homogeneity of the coating; the Al–Si–Na bath is favoured. For samples of equal thickness, the minimum coating times for these five steels were found to be similar. As the carbon content increased the diffusion rate was found to decrease. (16 references).—P. S.

Hot Dip Wire Aluminizing Processes and Alloys. J. D. Sprowl. (*Wire and Wire Products*, 1956, **31**, Oct., 1160–1163, 1273). Steel wire coating is described and structures illustrated.

Titanium Coatings of Metals and Ceramics. M. E. Straumanis and A. W. Schlechten. (*Metall*, 1956, **10**, Oct., 901–909). A new method is described for the coating with titanium of iron, mild steel, copper, nickel, cobalt, gold, platinum, silicon, porcelain, and sintered alumina. The objects are dipped in molten sodium chloride containing a metallic dispersion of titanium. The properties of the coating and the mechanism of deposition of titanium are described. Possibility of extending the technique to coating with chromium, uranium (on copper), zirconium, and hafnium, are alluded to.—J. G. W.

An Electrochemical Method of Oxide Coating of Iron and Steel in a Hot Concentrated Alkali Solution. V. V. Losev. (*Zhur. Priklad. Khim.*, 1956, **29**, (6), 948–950). [In Russian]. Optimum conditions for anodizing iron and steel objects are given.—V. G.

New Continental Phosphating and Cleaning Processes. (*Indust. Finishing*, 1956, **9**, Oct., 140–142). The Atram phosphating process, the Grisiron alkaline cleaners, and the ASL metal drying process have been introduced into this country, also the Petrinol cleaning process. The Roto-Ram deburring process is also mentioned.

The Nickel Dip: a Radioisotope Study of Metallic Deposits in Porcelain Enamelling. J. C. Richmond, H. B. Kirkpatrick, and W. N. Harrison. (*NACA TN* 3577, 1956, pp. 27; TIDU List 624).

Improvement of Resistance to Oxidation and Wear of Metal Surfaces by Non-electrolytic Nickel Plating. A. Portalupi and E. Melgara. (*6th Internat. Mech. Eng. Congress*, 1956, reprint C3/9, pp. 14). Brenner and Riddel's process is described and evaluated.

The Main Characteristics of Phosphorus-Nickel Alloy, its Physical and Electrical Properties and Use in Various Industries. R. Studler. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C3/15, pp. 6). Kanigen plating (non-electrolytic Ni) is described and its properties noted. It contains 7–10% P.

Hot Dip Galvanizing 1946–1956. M. L. Hughes. (*Product Finishing*, 1956, **9**, July, 181–191; Aug., 61–67). A comprehensive review of technical developments in galvanizing. Preparatory treatments, the hot dipping operation and the galvanizing of sheet, strip, wire and tube are discussed. (281 references).—A. D. H.

A Survey of Literature on Hot Dip Galvanizing, 1950–1955. J. J. Sebisty. (*Canad. Mines Techn. Surveys.* 1956, Report PM 202, April 23, pp. 60). (109 references).

Hot-Dip Galvanizing. The Process and its Use as a Protection

Against Corrosion. Haarman. (6th *Internat. Mech. Eng. Congress*, 1956, preprint C1/3, pp. 16). Degreasing, pickling, treatment of wire, sheet, strip, pipes, hollow ware, etc. and testing methods are considered and the nature of the protection and limits of application outlined.

New Hot-Dip Galvanizing Plant. (*Corrosion Techn.*, 1956, **3,** Dec., 397–399). An account of the capacity and performance of the new plant installed in the works of Ideal Casements Ltd. is given. The metallurgical and engineering aspects are considered followed by descriptions of the pickling, washing, fluxing, drying, galvanizing and etching procedures.—L. E. W.

Electro-Zinc Coated Sheet. F. H. Smith. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C2/14, pp. 17; *Metal Ind.*, 1956, **89,** Nov. 30, 453–455). Processes and corrosion resistance are reviewed. Plant used, applications and uses, deep drawing and welding, painting and finishing are briefly considered.

Adhesion of Electrolytic Zinc Deposits. K. M. Gorbunova and P. D. Dankov. (*Zhur. Fiz. Khim.*, 1953, **27,** (11), 1725–1730). Work of separation was measured by direct pulling off of coatings and the resulting surfaces examined for the plane of weakness. Breakage occurs across the zinc crystallites in all cases, close to the surface of contact. Theory in terms of surface energy is discussed.

Electrogalvanizing from the Pyrophosphate Bath. J. Vaid and T. L. Rama Char. (*J. Sci. Indust. Res.*, 1956, **15B,** Sept., 509–515). Deposits comparable to those from cyanide baths may be obtained from solutions of zinc pyrophosphate. The experimental procedure is given and the results discussed.

Industrial Electrodeposition of Zinc on Steel Plate—Advantages of the Process—Results Obtained—Critical Examination of Behaviour Against Corrosion—Field of Application. G. Pieltain, J. Deheneffe and P. Lemal. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C2/12, pp. 13). Phosphating and chromating as a base for painting are included.

Practical Ideas on Chemical and Electrodeposits of Metals for Protection Against Corrosion. F. Enrico and V. Riccio. (*6th Internat. Mech. Eng. Congress*, 1956, preprint, C2/5, pp. 11). Work at FIAT on Cd and Zn on steel is described and salt spray test results given. Tinning, nickel plating and passivation are included. Treatment of Mg alloys is also outlined.

Developments in Tin and Tin Alloy Plating 1946–1956. J. W. Price. (*Product Finishing*, 1956, **9,** July, 135–142). The status of methods for the electrodeposition of tin and of tin alloys with nickel, zinc, cadmium, lead and copper is assessed and developments in these processes since their inception are reviewed. (33 references).—A. D. H.

Cathodic Efficiency of Alkaline Copper [Plating Baths]. L. Ades. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C2/17, pp. 11).

Rochelle Salt Alkaline Copper Plating Bath. M. Mercadov. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C2/9, pp. 12).

Lead Coatings—Forgotten Metal Coatings. J. Teindl. (*Hutnik*, 1955, **5,** (11), 344–345). An account of a process previously worked at Neudeck is given. The importance of surface preparation and pickling are discussed and the possibilities of electrolytic lead coatings considered.

The Theory of Metal Spraying Processes. G. G. Caccia. (*Ing. Mecc.*, 1956, **5,** June, 23–28). [In Italian]. This article examines the theory of the metal spraying process and discusses the properties of the sprayed surface and the physical characteristics of the coating.—M. D. J. B.

Developments in Sprayed Metal Coatings. (*Corrosion Techn.*, 1956, **3,** Oct., 321–322). A new powder gun is briefly described and illustrated. The properties, applications and limitations of self-fluxing and oxidation-resistant alloys and ceramics are discussed.—L. E. W.

The Trend of Metal Spraying Practice. W. E. Stanton. (*Corrosion Techn.*, 1956, **3,** Oct., 311–313). The author considers the factors affecting pistol size and describes briefly the advantages and applications of mechanical spraying. The facilities available for metal spraying in Britain are outlined.

Mechanisation of the Metal Spraying Process. H. J. Plaster. (*Electroplating Metal Finishing*, 1956, **9,** Oct., 323–328). The development of machines for automatic metal spraying is described. Examples of machines for spraying structural steel joists, tubes and steel boxes are given.—A. D. H.

Metallized Coatings for Heat Corrosion Protection. J. R. Franklin. (*Corrosion Techn.*, 1956, **3,** Oct., 326–327). The author is concerned mainly with the applications and limitations of iron–aluminium coatings and three of the processes by which such coatings can be applied. In the first the aluminium is sprayed directly on to the steel surface. In the second the aluminium is held in suspension in a paint-type sealer, the only metallizing being a thin layer of nickel-chromium alloy. The third process involves spraying first with nickel-chromium alloy, then with aluminium and, finally, a paint-type sealer is applied on the outside.—L. E. W.

Sprayed Aluminium and Zinc in Corrosive Environments. R. E. Mansford. (*Corrosion Techn.*, 1956, **3,** Oct., 314–316). The author first describes briefly the structure of sprayed metal coatings, their general characteristics and spraying techniques. Then the properties of sprayed aluminium and zinc coatings are dealt with in some detail and their advantages and limitations are discussed. Aluminium sprayed by the wire and molten metal processes gives excellent protection in normal industrial atmospheres in which sulphur oxides are the predominating corrosive influence. In hard waters aluminium does not give such satisfactory service as zinc; both afford good protection in sea water. Sprayed zinc is widely used in atmospheres where the sulphur pollution is low. (15 references).

Notes on Plating by Means of Oxy-Acetylene or Oxy-Propane Hot Metal Spraying. Cauchetier. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C1/1, pp. 9). The mechanism of adhesion is discussed and anodic and cathodic metals considered on steel.

Structure of Oxide Scales on Nickel-Chromium Steels. H. J. Yearian, H. E. Boren, jun. and R. E. Warr. (*Corrosion*, 1956, **12,** Nov., 561–568). The structures of the scales formed on a series of typical Ni–Cr steels when oxidized for 100 hours in air at 1600 to 2200° F were investigated by X-ray diffraction methods. The scales are of two types, the principal constituent of the more protective type is Cr_2O_3. A solid solution of Fe_2O_3–Cr_2O_3 may also be present, more Fe_2O_3 being related to higher rates of attack. At low attack rates, fractional percentages of Mn in the alloy give considerable amounts of $MnCr_2O_4$ in the scale. This is replaced by a Ni–Cr–Fe spinel as the attack rate rises. At excessive rates of attack the less protective type of scale is formed. This contains no Cr_2O_3 phase but Fe_2O_3–Cr_2O_3 solid solutions and Ni–Cr–Fe spinels. The composition varies through the scale. These observations are related to existing data and interpreted using a theory of selective oxidation and depletion.—J. F. S.

Application of Phosphatisation. J. Demesse. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C3/3, pp. 6). Zinc, manganese and especially the iron phosphate processes are described and classified, particularly according to weight of coating.

Applications of Phosphatation to Friction Surfaces. R. Lagarde. (*6th Internat. Mech. Eng. Congress*, 1956, preprint A2/15, pp. 9). Measurement of friction with and without phosphatation are tabulated.

Surface Treatment by Phosphatisation before Cold Forming. Lefevre. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C3/7, pp. 10). The process is outlined and savings in time and costs set out.

Various Applications of Phosphatation in Mechanical Industries. R. Lagarde. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C3/12, pp. 10). Thick and thin coatings are considered; painting, and use in cold forming are mentioned.

Phosphatation and Anticorrosion. R. Lagarde. (*Corrosion et Anti-Corrosion*, 1956, **4,** Sept., 289–296). The chemistry, layer structure and processes are briefly described and illustrated, and control, kinds of coating formed and uses on non-ferrous metals are mentioned.

New Developments at Roto-Finish. (*Corrosion Prevention and Control*, 1956, **3,** Nov. 41–43). Precision barrelling techniques are described and their introduction from U.S. Roto-ram deburring, phosphating by Hoechst process and the Petrinol metal cleaner and ASL metal dryer are briefly reviewed.

Influence of Copper Ions on Adherence of Vitreous Coatings to Stainless Steel. D. G. Moore and A. G. Eubanks. (*NACA TN* 3679, 1956, pp. 15; TIDU List 624). Copper ions increased adhesion, the effect decreasing with increased firing times and temperatures. Mechanism is discussed.

Reliability of Indirect Measurement of Enamel Thickness. V. Montoro, E. Lossa, A. Giussani, and E. Giussani. (*Fonderia Ital.*, 1956, **5,** July, 269–271). [In Italian]. The authors study surface defects in enamels and show that these are more numerous where enamel thicknesses are small. A detailed

statistical analysis is made of the distribution of defects in a bath tub, showing the parts with high incidences of faults.

The Protection of Structures and Plant From Chemical Corrosion by Vinyl Resin-Based Paints. F. A. S. Wood. (*Corrosion Prevention and Control*, 1957, **4**, Jan., 43–45).

Quality of Lacquered Blackplate Cans as a Function of the Baking Temperature of the Lacquer. J. Herrmann and B. Müller. (*Technik*, 1956, **11**, Nov., 773–776). Results of investigations are reported in which short-term corrosion tests with various concentrations of salt and acetic acids served as a measure of the quality of lacquered black plate. Results of these and of physical properties are fully tabulated.

Neoprene and Hypalon as Coatings. N. L. Catton. (*Indust. Finishing*, 1956, **9**, Oct., 159–160). Uses of two synthetic rubber coatings are reviewed.

Temporary Protective Coatings for Metals. I.—Lanolin-Containing Materials. E. Strong. (*Product Finishing*, 1956, **9**, Sept., 50–58, 116). The characteristics of lanolin dissolved in mineral oil as a temporary rust preventative coating are given and compared with petroleum hydrocarbon oils. Details of equipment for corrosion testing are shown in detail. **2.—Protection in Transit and Storage.** (Oct., 86–99). An account is given of corrosion at different places with varying climates and under conditions of transport by road and rail. Storage systems with their weaknesses are described and protective measures and compositions are given. **3.—Corrosion Control by Cathodic Protection.** (Nov., 82–95, 128). Electrode potentials of metals and alloys and safe metallic combinations are tabulated. Effects of ion concentration and polarization curves for various protective systems are shown and cathodic protection systems are indicated for grease-coated or enamelled pipelines. **4, 5.—Essential Requirements.** (Dec., 68–75; 1957, **10**, Jan., 79–91). Various conditions and criteria are listed and tables are given of lanoline and hydrocarbon oil compositions with the effects of humidity and other laboratory tests, viscosity, and other properties.

Protecting Steelwork. Problems Overcome at Manvers Main Coke Plant. (*Iron Steel*, 1957, **30**, Jan., 31–32). Painting systems developed for various locations are outlined.

Protection by Zinc Powder Anti-Rust Paints. G. Binetti. (*Acciaio Costruzioni Met.*, 1956, **8**, Jan.-Feb., 17–32). [In Italian]. After a brief review of the chemistry of corrosion, the author discusses surface protection by means of paints on a zinc powder base. The characteristics of these paints as well as their limits of application are described. Test results, both accelerated and long-term, are given and the electrochemical properties of the paints are examined.

POWDER METALLURGY

The Study of the Production of Spongy Iron Powders by Reduction of the "Fluosolid Cinders" as the Precipitant of Copper from Copper Sulphate Solutions. K. Kabayashi. (*Tetsu to Hagane*, 1956, **42**, Mar., 170–172). [In Japanese]. Results are given for the efficiency and time of reduction of samples containing 38% and 48% of iron, respectively, by H_2, CO, modified town's gas, water-gas, etc.—K. E. J.

On Sintering Non-Single-Phase Bodies. I. Sintering Together of Non-Uniform Grains. II. Sintering of Compressed Mixtures of Powders. Dependence of Shrinkage on Concentration. B. Ya. Pines and N. I. Sukhinin. (*Zhur. Tekhn. Fiz.*, 1956, **26**, (9), 2086–2099, 2100–2107).

Factors Disturbing Normal Shrinkage during Sintering of Metallic Powders. I. M. Fedorchenko. (*Zhur. Tekhn. Fiz.*, 1956, **26**, (9), 2067–2075). [In Russian]. The influence of the presence of reducible and irreducible oxide films, gas evolution, and phase transformations on the shrinkage process during sintering of briquetted metallic powders (including iron) was investigated. The negative influence of phase transformation of Ac_3 in briquettes from iron powder increases with increasing density and cannot be removed by subsequent heating to 1050–1100° C.—V. G.

Some Regularities in Mechanical Strength of Bodies Obtained by Sintering Metallic Powders. B. Ya. Pines and N. I. Sukhinin. (*Zhur. Tekhn. Fiz.*, 1956, **26**, (9), 2076–2085). [In Russian]. An investigation of mechanical strength of sintered single and two-component mixtures of metallic powders (copper, copper + tungsten, molybdenum or iron) was carried out. The dependence of tensile strength and elongation on porosity and sintering temperature was determined.—V. G.

Some Regularities in Mechanical Properties of Specimens Produced by Sintering Metallic Powders. II. Investigations at Elevated Temperatures. B. Ya. Pines and A. F. Sirenko. (*Zhur. Techn. Fiz.*, 1956, **26**, (10), 2378–2386). [In Russian]. Tensile strength tests of sintered specimens from compressed metallic powders (copper, copper–iron, and copper–nickel) at temperatures up to 900° C were carried out. The results obtained are discussed.—V. G.

Replacement of Castings by Powder Metallurgy. T. L. Robinson. (*Proc. Metal Powder Assoc., 12th Annual Meeting*, 1956, 22–25). Grey iron castings are replaced.

High Density Iron Powder Parts. W. J. Doelker. (*Proc. Metal Powder Assoc. 12th Annual Meeting*, 1956, 65–70). Structures and mechanical properties are given.

Medium Density Sintered Structural Materials. R. Talmage. (*Proc. Metal Powder Assoc. 12th Annual Meeting*, 1956, 63–65). High-copper high-carbon steel parts by powder metallurgy are described.

Copper or Copper-base Infiltration of Iron Parts. C. G. Johnson. (*Proc. Metal Powder Assoc. 12th Annual Meeting*, 1956, 70–76). Composition, structures, and properties are given.

Influence of Lubrication and Die Surface on the Pressing Characteristics of Metal Powders. I. Ljungberg and P. G. Arbstedt. (*Proc. Metal Powder Assoc., 12th Annual Meeting*, 1956, 78–91). Purpose, effects, and types of lubricants are briefly reviewed and the effects of zinc stearate on compacted iron powders and on ejection force, and also other lubricants is discussed. Other properties of pressed and sintered irons are given with various lubricants.

FERRITES, CERMETS, AND CARBIDES

Angles between Partial Magnetizations in Spinel Ferrites containing Manganese Ions of more than One Valency. W. P. Osmond. (*Phil. Mag.*, 1956, **1**, 12th Series, Dec., 1147–1156).

On the Stability of the Compound CaO, $2Fe_2O_3$. P. Batti. (*Chim. e Indust.*, 1956, **38**, Oct., 864–866). The compound is stable 1130–1230° C approx.

Cation Arrangement and Magnetic Properties of Copper Ferrite–Chromite Series. S. Miyahara and H. Ohnishi. (*J. Phys. Soc. Japan*, 1956, **11**, Dec., 1296–1297).

Effect of Additions on the Magnetic Properties of PbO–Fe_2O_3 System. H. Kojima. (*Sci. Rep. Tôhoku Univ.*, 1956, **8**, Dec., 540–546).

PROPERTIES AND TESTS

A Reconciliation of Certain Recovery Properties in Metals. A. J. Kennedy. (*J. Mech. Phys. Solids*, 1956, **4**, May, 162–166). A relaxation-type model is proposed which agrees with time and temperature functions proposed from time to time to represent mechanical and electrical properties.

Universal Testing Machines. (*Wire Ind.*, 1956, **23**, July, 620). Tarnogrocki machines are described.

Defects in Steel Products Attributable to Steelmaking. J. B. Kelly. (*J. Australian Inst. Met.*, 1956, **1**, May, 1–6). Internal and external defects are defined in the terms of B.S. 2094, Part 2. The process of ingot solidification is described in some detail and the formation of pipes and blowholes is considered as well as segregation, inclusions, and splash.

Corner Fractures in Explosively Loaded Thin-walled Stee Cylinders. S. Singh. (*Brit. J. Appl. Phys.*, 1956, **7**, Dec., 453–454). A ring of fragments is emitted at 45°.

Measurement of Lengths and Thickness by Electronic Methods. (*Usine Nouvelle*, 1956, **12**, Sept. 20, 86–87, 89). Apparatus is briefly reviewed.

A Survey of Surface Finish Inspection Techniques. C. H. Good. (*Steel Processing*, 1956, **42**, Nov., 641–644, 648–650). The capabilities and limitations of various surface finish techniques are discussed. These include reflectivity meters, air gauges, sectioning, shadow microscopes, interference microscopes, stylus profiling, and stylus averaging equipment.

The Fielden Proximity Meter. Applications of Capacitance Measurement in Research and Industry. (*Process Control Automation*, 1956, **3**, Aug., 278–283). Many uses are indicated including strain gauging, surface gauging, and as a paint thickness gauge.

Significance of Materials for Technology. E. Schmid. (*Z. VdI.*, 1956, **98**, Aug. 11, 1355–1363). Interaction of technological needs and developments of materials is illustrated by means of examples which include heat and corrosion resistant

steels, magnetic alloys, semiconductors, light alloys, and plastics. The needs of nuclear reactor technology are discussed in some detail and some of the effects of irradiation on metal properties are touched upon.—J. G. W.

Destructive and Non-destructive Testing. F. T. Galton. (*Inspection Eng.*, 1957, **21**, Jan.-Feb., 10–14). An elementary account of the principal methods of testing, with a section on welding faults.

Stress-concentration Factors in Shafts Containing Transverse Holes and Subjected to Bending. H. Okubo and K. Takai. (*J. Appl. Mech.*, 1956, **23**, Sept., 478). An investigation by the plating method is summarized.

Some Theoretical and Practical Considerations on Plastic Bending. R. Levi. (*Ing. Mecc.*, 1946, **5**, April, 23–27; May, 5–15; June, 51–64). [In Italian]. This paper discusses the problem of plastic bending of mild steel sheets. Simple bending and bending under tension are examined both qualitatively and quantitatively and formulæ are suggested linking bending strains, variations in thickness, axial loads and bending moments. The position of the neutral fibre has been studied closely. The author puts forward an analytical solution involving the resolution of equations and a graphical method based on the intersection of lines representing the curvature of the sheet and its plastic behaviour.—M. D. J. B.

Bend: Tensile Relationships for Tool Steels at High Strength Levels. J. C. Hamaker, jun., V. C. Strang and G. A. Roberts. (*Trans. Amer. Soc. Metals*, 1956, **49**, Preprint 25). Two W–Cr tool steels of medium and high carbon contents were tested for tension and bending (single and double point loading). From 30 to 55 Rockwell 'C,' tensile strength was equivalent to 45–50% of double bend strength, while 0·2% offset tensile yield strength equalled about 88% of bend yield strength. There was a decrease in the modulus of elasticity with increase in hardness. Curves are given and the results discussed.

Correlation of Tensile Properties with Microstructure for Some 3% Nickel Steels. J. P. Hugo and J. H. Woodhead. (*J. Iron Steel Inst.*, 1957, **186**, June, 174–188). [This issue].

Notch Ductility of Malleable Irons. G. A. Sandoz, N. C. Howells, H. F. Bishop and W. S. Pellini. (*Trans. Amer. Soc. Metals*, 1956, **49**, Preprint 6). The notch ductility of ferrite iron is impaired by the presence of phosphorus, carbides and primary graphite while the nil ductility transition temperatures of commercial ferritic irons (up to 3 in. in thickness) compare favourably with those of other unalloyed ferrous materials. The nil ductility transition temperatures of pearlitic irons are higher than those of ferritic irons and are affected by hardness, method of heat treatment and phosphorus content. Similar results have been obtained for nodular irons and for steels.—E. E. W.

The Effect of Sub-boundaries and Carbide Distribution on the Notch Toughness of an Ingot Iron. J. C. Danko and R. D. Stout. (*Trans. Amer. Soc. Metals*, 1956, **49**, Preprint 5). With constant sub-grain size the Charpy **V**-notch transition temperature of the ferrite increases approximately 20° F with an increase in one ferrite grain size number. At the same ferrite and subgrain size, annealed and solution-treated iron has a transition temperature approximately 100° F lower than in the as-annealed condition because segregation of carbides at the primary ferrite grain boundaries is eliminated and the segregation of carbides and impurities in the sub-boundaries is reduced.—E. E. W.

Dynamic Biaxial Stress-Strain Characteristic of Aluminium and Mild Steel. G. Gerard and R. Papirno. (*Trans. Amer. Soc. Metals.*, 1956, **49**, Preprint 2). A new technique is described which utilizes an impact tube for rapidly applying a pressure wave to a diaphragm. The specimen response is measured in terms of strain and deflection. Comparison is made with other techniques.—E. E. W.

Flattening Tests of High Carbon Chromium Steel Tube for Ball Bearing Race. E. Miyoshi and K. Kawano. (*Sumitomo Metals*, 1956, **8**, Apr., 75–85). [In Japanese]. The flattening test is used to assess ball-bearing steel tubes; the total load when cracks appear is the flattening value, and is a measure of the toughness of the hardened steel. The effects of microstructure before quenching, quenching and tempering, flattening speed, homogenizing, size of test-piece, etc. on this value are assessed. Results are compared with those from elastic theory. Cold-drawn tube after softening was harder than hot-finished tube, but its flattening value was no less.

Calibration of High-pressure Test Standards. (*Engineer*, 1956, **202**, Nov. 16, 713–715). A review of N.B.S. work on the deadweight piston gauge and the use of wire resistance gauges for use at phase-transition points.

Symposium on Impact Testing. (*Amer. Soc. Test. Mat. Special Publ. No.* 176, 1956). **Notched-Bar Testing-Theory and Practice.** S. L. Hoyt. (3–9). Steel rating and selection with avoidance of dangerous notches is discussed, and the effect of notches is briefly considered. **Transition Behaviour in V-Notch Charpy Slow-Bend Tests.** C. E. Hartbower. (10–24). Three structural steels representing the full range of deoxidation practice and manganese steels with 0·04–0·45% C and 0·43–1·05% Mn were used at a range of temperatures, noting lateral expansion, appearance, deformation and fibrosity at fracture. Crack initiation and propagation stages were differentiated by defining a transition temperature function. **Effects of Manganese and Aluminium Contents on Transition Temperature of Normalized Nickel Steel.** T. N. Armstrong and O. O. Miller. (25–39). Bars rolled from steels made in a small induction furnace under closely controlled conditions were used. Charpy impact data are tabulated. **Low Temperature Transition of Normalized Carbon-Manganese Steels.** T. N. Armstrong and W. L. Warner. (40–58). **Effect of Specimen Width on the Notched-Bar Impact Properties of Quenched-and-Tempered and Normalized Steels.** R. S. Zeno. (59–69). Energy and deformation transition temperature are lowered as width decreases. **Reproducibility of Charpy Impact Test.** D. E. Driscoll. (70–75). It is concluded that the test can be made accurate and reproducible. Deviations reported are discussed. **Automatic Impact Testing from Room Temperature to − 236° C.** T. S. De Sisto. (76–83). A high-vacuum liquid N_2 or He-cooled apparatus is described and results shown. **The Influence of Pendulum Flexibilities on Impact Energy Measurements.** J. I. Bluhm. (84–93). A mathematical and experimental analysis suggesting that flexibility may be a source of error and suggesting criteria for adequate rigidity. **The Impact Tube: A New Experimental Technique for Applying Impulse Loads.** G. Gerard. (94–110). A type 302 stainless and an annealed low-carbon steels were examined. The theory and aerodynamics of the shock tube are given.

Factors Affecting Impact Properties. H. Schwartzbart and J. P. Sheehan. (*Iron Age*, 1956, **178**). The results of a comprehensive investigation into the impact properties of quenched and tempered low alloy steels are presented.

1. How Carbon Content Affects Impact Properties. (Aug. 9, 85–89). The steels investigated are specified and the effect of carbon and alloy content on impact strength are reviewed.

2. How Boron, Grain Size Affect Impact Properties. (Aug. 16, 102–106). The effect of boron additions and grain size, also molybdenum/phosphorus ratio, are considered. Steels at high strength levels benefit greatly from boron additions as regards transition temperature.

3. How Fracture Type, Specimen Size Affect Impact Properties. (Aug. 23, 107–110). In martensitic structures both ductile and brittle fractures can frequently be traced to tempering temperature. The effect of specimen size is generally more pronounced at higher hardnesses.—D. L. C. P.

Impact Testing and Risk of Brittle Fracture. C. Schaub. (*Tek. Tidskr.*, 1956, **86**, Sept. 25, 793–797). [In Swedish]. Based on the recommendations of the International Institute of Welding, draft Swedish Standards for pressure vessel and structural steels have laid down minimum Charpy **V**-notch values of $\geqslant 2{\cdot}6$ kpm/cm² at − 20° C or 0° C. This means that relatively dear steels will have to be used in cases where cheaper steels previously sufficed. The author considers these standards as too stringent and gives his reasons for this view. He discusses the relationship between the Charpy **U** and **V** impact tests, impact toughness, brittle fracture limit and other strength characteristics of steels.—G. G. K.

Relationship Between Nominal Cleavage Strength and Temperature. T. Noren. (*Dansk. Tekn. Tidsskr.*, 1956, **80**, (9), 237–243). [In Danish]. A certain relationship has been observed between nominal cleavage strength and temperature, also between cleavage strength and certain impact strength curves for the corresponding steels. It has now been shown that if we consider the mainly contraction-free portion of the nominal cleavage strength curve this—like the yield-point curve (and probably the Charpy **V**-impact strength curve) is an exponential function of temperature. Equations are presented to illustrate this fact and its significance discussed.

Impact Characteristics and Mechanical Properties of Leaded and Non-leaded C-1050 and C-1141 Steels. A. P. Weaver.

(*Trans. Amer. Soc. Metals*, 1956, **49**, Preprint 22). Only slight differences were noted in Brinell hardness and tensile properties of leaded and non-leaded steels of identical compositions but the Charpy **V**-notch transition temperatures were consistently lower on the leaded types. This is explained by the grain-refining properties of lead.—E. E. W.

Impact Phenomena at High Speeds. M. E. van Valkenburg, W. G. Clay, and J. H. Huth. (*J. Appl. Phys.*, 1956, **27**, Oct., 1123–1129). Experiments are described which relate the mechanisms of cratering and the perforation of thin targets when studying high speed metal-to-metal impacts using spherical pellets of steel, Al, brass, Mg, Pb and Zn. The volume of the crater per unit energy of the impacting pellet is essentially constant for each material and the penetration is proportional to the velocity (up to the velocity of sound in the target material).—E. E. W.

Study on Spring Materials. VI. H. Hotta, T. Kawasaki and K. Hori. (*Tetsu to Hagane*, 1956, **42**, Apr., 333–337). [In Japanese]. Impact, fatigue, hardness and other tests showed that, for No. 5 die steel, quenching from 1100° C in a constant-temperature bath at 600° C was the best heat-treatment for use as a spring material. In impact hardness testing of ordinary quench-tempered Si–Mn steel, an inverse linear relationship was found between impact hardness and testing temperature.—K. E. J.

A Comparative Study of Our Carburizing Steels. R. Štefec and J. Dobrý. (*Hutnické Listy*, 1956, **9**, (9), 536–541). [In Czech]. A study of the impact strengths of 10 Czechoslovak carburizing steels at room temperature and low temperatures was carried out. The steels were tested before and after carburizing. The impact strength in the region around 0° C was found to depend significantly on the nickel and carbon contents.—P. F.

The Bauschinger Effect on Columns. P. C. Paris. (*J. Appl. Mech.*, 1956, **23**, Sept., 479–480). Effects of shock waves on structural steel members are investigated.

Fatigue and Its Relations to the Mechanical and Metallurgical Properties of Metals. G. R. Gohn. (*Trans. Soc. Auto. Eng.*, 1956, **64**, 31–40). Fatigue properties are compared with other mechanical tests but no adequate correlation is found. Theories of the mechanism are discussed and factors increasing resistance are reviewed.

Theory of Fatigue Fracture. A. A. Kheiralla. (*J. Appl. Mech.*, 1956, **23**, Sept., 473–474). A criticism of the reaction kinetic argument of Yokobori.

The Propagation of Fatigue Cracks. A. K. Head. (*J. Appl. Mech.*, 1956, **23**, Sept., 407–410). A theoretical analysis previously advanced is discussed in the light of experimental findings and extended to the case of large stresses.

On the Frequency Dependence of the Fatigue of Metals. T. Yokobori. (*J. Phys. Soc. Japan*, 1956, **11**, June, 715–716). Discrepancies between the predictions of the author's theory and findings by Head, (Ibid. 468) are discussed and an effect in hard steel explained.

The Influence of Design on Stress Concentrations and Fatigue Failure. A. G. Gardner. (*Machinery*, 1956, **89**, Nov. 9, 1061–1066). A general discussion on the avoidance of stress raisers, protection against corrosion fatigue and elimination of notches.

How Shot Peening Improves Fatigue Stength. H. J. Grover. (*S.A.E.J.*, 1956, Aug., 28–30). Surface roughening, work-hardening, and residual stress production are considered as causes of the increase in fatigue resistance.

Effect of Annealing at 650° C on the Bend Fatigue Strength of Large Welded Constructions. P. E. Wiene. (*Dansk Tekn. Tidsskr.*, 1956, **80**, (4–5), 135–139). [In Danish]. Three groups of tests were made on plates 28 and 22 mm thick after they had been electrically welded, to determine their bending strength in comparison with other test plates which had been annealed at 650° C for 4 hours, followed by 20 hours controlled cooling. Test equipment and methods are described. The results show that fatigue strength is increased by 20% by such annealing, this evidently offering advantages for welded steel components containing 0·17% C and probably for all steels with more than 0·14% C when such components are exposed to high, fluctuating stresses and where the maximum stress occurs at the surface of the material.—G. G. K.

Relation of Inclusions to the Fatigue Properties of SAE 4340 Steel. H. N. Cummings, F. B. Stulen and W. C. Schulte. (*Trans. Amer. Soc. Metals*, 1956, **49**, Preprint 23). An explanation is proposed concerning the mechanism of failure. Various predictions are made, e.g. the first microcrack will be associated with a large inclusion but the final fracture may not be associated with the first crack; the number of cracks on the surface of a " failed " specimen will increase with stress level; if all the small inclusions could be eliminated the life at very high fatigue over-stresses could be increased by a large amount; if only the large inclusions were eliminated the life for a low fatigue over-stress would be increased greatly.

High-Temperature Materials. Metals and Alloys for Aircraft-Engine Construction. H. E. Gresham. (*Engineering*, 1956, **182**, Dec. 28, 818–820). Fatigue and creep strength data on nickel and other alloys are given.

An Evaluation of Creep Tests. R. Pospíšil. (*Hutnické Listy*, 1956, **9**, (9), 547–551). [In Czech]. Larson and Miller's method for the extrapolation of short time creep tests to long time values was applied to two steels containing 18% Cr, 9% Ni + Ti and 13% Cr, 12% Ni, 1% W + Ti, as well as to Nimonic 80A. The scope of the method is analysed.—P. F.

Interpretation of Creep Data. J. H. M. Draper. (*Iron Steel*, 1956, **29**, Nov., 511–516). The author gives a general picture of creep data of different types, indicating those which he considers preferable, and discusses the interpretation of the results obtained. Attempts to forecast creep strength are briefly reviewed.—G. F.

Metallographic Investigation of Creep Tests. F. Wever and A. Krisch. (*Forsch. Wirts. Nordrhein-Westfalen*, 1956, No. 315, pp. 25). Austenitic low-carbon chromium (16–17%) nickel (11–13·5%) steels and 0·13 and 0·23% C steels were examined before and after creep testing. Carbides were isolated and examined with X-rays. Small amounts of Ti, Mo-Nb and Nb were also present. Carbide composition altered during testing, the isolates consisting finally mainly of the stabilizing elements. Sigma phase appeared in the austenitic Cr Ni Mo Nb steel only at and above 650°, the three Cr Ni Nb steels showed none even after 7500 h and the ferritic steels showed increased carbides but without structural charge.

The Effect of Cold Work on the Creep-Rupture Properties of a Series of Simple 18–8 Type Stainless Steels. F. B. Cuff, jun., and N. J. Grant. (*J. Iron Steel Inst.*, 1957, **186**, June, 188–197). [This issue].

Time-dependent Tangent Modulus Applied to Column Creep Buckling. R. L. Carlson. (*J. Appl. Mech.*, 1956, **23**, Sept., 390–394).

The Creep and Creep-rupture Properties of 2¼ Cr–1 Mo Steel. S. Terai. (*Sumitomo Metals*, 1956, **8**, July, 164–177). [In Japanese]. This steel is used for superheater tubing and steam piping in power stations, Full annealing at 900° C or above gives stable creep properties under stress of 3·5 kg/mm². Values are given for creep and rupture strength for a life of 100,000 hours, and mechanical properties of ruptured specimens. Specimens ruptured after longer times at higher temperatures showed spheroidization and recrystallization in the microstructures.—K. E. J.

Effect of Environment on Creep-Rupture Properties of Some Commercial Alloys. P. Shahinian. (*Trans. Amer. Soc. Metals*, 1956, **49**, Preprint 34). Rupture life and minimum creep properties of DM 45, 12% Cr–V steel, AISI 304, N-155, S-816 and Inconel X were found to be affected by the environment (air, oxygen, nitrogen, helium and vacuum). Various explanations are discussed.—E. E. W.

Changes in Structure of Chrome-Nickel-Molybdenum Steels in Long Period Stress Creep Tests at 500°. F. Wever, A. Krisch and H.-J. Wiester. (*Forsch. Wirts. Nordrhein-Westfalen*, 1956, No. 314, pp. 35). Six steels Cr 0·48–0·93%, Mo 0·72–0·94% and Ni 1·42–1·60% were subjected to various heat treatments and their properties determined and structures examined. Creep tests were carried out to fracture and the carbide phases isolated, analysed, and examined by electron micrography. Conclusions are summarized.

A Preliminary Study of the Fatigue of Metals in Liquid Metal Environments. J. W. Martin and G. C. Smith. (*Metallurgia*, 1956, **54**, Nov., 227–232, 238). The possible increasing use of liquid metal coolants emphasizes the importance of a knowledge of the fatigue properties of metals and alloys in contact with liquid metals. The results of fatigue tests at room temperature on amalgamated copper alloy, and at 300° C on mild steel and stainless steel in contact with liquid tin and liquid sodium respectively are discussed.—B. G. B.

Statistical Investigation of the Fatigue Life of Deep-Groove Ball Bearings. J. Lieblein and M. Zelen. (*J. Res. Nat. Bur.*

Stand., 1956, **57,** Nov., 273–316). Pooled test data from manufacturers are exhaustively treated and examples worked out in appendices.

An Unusual Fatigue Failure. J. H. Slagg and E. Wood. (*Metallurgia*, 1956, **54,** Nov., 260). The fatigue failure of a hammer head is discussed. The possibility of fatigue spreading outwards from an internal clink is considered.—B. G. B.

Automatic Hardness-testing. (*Machinery*, 1956, **89,** Oct. 26, 954–956). Reicherter equipment at Vauxhall Motors is described. Gudgeon pins of three sizes are tested.

The Use of Microhardness Tests for the Study of Sintered Materials. G. Carro Cao. (*Met. Ital.*, 1956, **48,** Aug., 270–272). [In Italian]. The author describes hardness tests carried out on powders compressed at different pressures and is able to draw conclusions relating to the tamping pressure to the final characteristics of the sintered material.—M. D. J. B.

The Temperature Dependence of the Hardness of " Pure " Iron and Various Ferrite Steels. F. Garofalo, D. C. Marsden and G. V. Smith. (*Trans. Amer. Soc. Metals*, 1956, **49,** Preprint 15). " Pure " iron, low-carbon commercial steels and types 430 and 446 steels exhibited hardness peaks associated with a strain-ageing reaction. Steels containing 8% Cr, 8% Cr–Mo and 12% Cr exhibited constant hardness over a range of 200° F also attributed to strain-ageing reaction. After purification of a low-carbon steel in wet hydrogen or suitable heat-treatment of 5%, 8% or 17% Cr steel containing Ti or Si, strain-ageing was eliminated and the hardness–temperature curve approached that of a " pure "–metal other than iron.

Effect of Skin Decarburization on the End-Quench Hardenability Test of Steels. A. Rose and L. Rademacher. (*Stahl u. Eisen*, 1956, **76,** Oct. 18, 1366–1369). Testing for hardenability and melt control by the end-quench method usually gives uniform and reproducible results, but, when applied to high-speed and other alloy steels, low hardness numbers and heavy scattering of the results were found. The carbon content is strongly reduced at the quenched face up to a depth of about 0·5 mm and reaches its original value only at more than 0·75 mm, whereas the circumference is only slightly affected. This effect is attributed to skin decarburization and is particularly noticeable in steels containing carbide-forming elements and having high austenite-transformation temperatures. The authors recommend deeper grinding of the specimens for hardness testing.—T. G.

Hardness Plateaux and Twinning in Steel by Explosives with Lined Cavities. Sampooran Singh, N. R. Krishnaswamy and A. Soundraraj. (*J. Appl. Phys.*, 1956, **27,** June 617–620). The impact of an element of a jet, squirted from high explosives with steel-lined conical cavities, on annealed low carbon steel appears to initiate a transient compressional stress wave which results in hardness plateaux and an increase in the number of twin directions with hardness. The plateaux are shown graphically and appear to be related to Neumann bands on the steel.—E. E. W.

Shape and Ageing Effects on the Life of Machine Parts. V. Mydlarčik. (*Sbornik vědeckych praci Vysoke škoły bańske v Ostravě*, 1955, **1,** (1) 56–63). Breakages in service are observed without evidence of plastic deformation which are due to stress concentrators, and transition from ductile to brittle fracture occurs. The mechanism of fracture under relatively low working load is described.

Deep Drawing Properties of Steel Strip. II. Effect of Aluminium on the Strain Ageing of Low-Carbon Steels. Y. Shinokawa, T. Fujii and S. Koteria. (*Sumitomo Metals*, 1956, **8,** July, 117–125). [In Japanese]. For aluminium-killed steel sheet, the elimination by skin pass of the increase in yield point does not occur after ageing at 100° C, and begins to occur above 200° C; for rimmed steel it occurs completely after ageing. Aluminium additions reduce yield strength and improve deep-drawing properties. Strain-ageing is complete in 10 minutes for aluminium-killed steel. The degree of quench ageing of aluminium-killed steel after quenching from 900–1200° C is increased with quenching temperature, probably because of decomposition of AlN and increase of nitrogen in ferrite. Isothermal recrystallization is complete in 1–2 hours. (11 references).—K. E. J.

Effect of Al, Ti and B Addition on the Low-temperature Tempering Embrittlement of Cr–Mn Case-hardening Steel. T. Akutagawa and K. Ogawa. (*Tetsu to Hagane*, 1956, **42,** Apr., 318–326). [In Japanese]. The effects of additions of Al–Ti, Ti and Al–Ti–B on impact values during tempering between 120° and 420° C, tempering embrittlement temperature, impact minimum and transition temperature are reported. The embrittlement arises from precipitation of a thin elongated cementite network along ferrite grain boundaries, and occurs at higher tempering temperatures when boron is added. (13 references).—K. E. J.

Effect of Carbide-forming Elements on Temper Embrittlement of Steel. V. I. Prosvirin and E. I. Kvashnina. (*Vestnik Mashinostroeniya*, 1955, **35,** (2), 58–67). Steels containing Mo, W, Nb, Ti and V are studied by impact methods and the development of temper brittleness followed and correlated to some extent with carbide separation and structure, particularly in W–Cr–Mn and W–Cr–Ni steels. Mo and W are shown to inhibit temper brittleness though in some compositions it reappears on long heat treatment. Ti, V and Nb do not, in general, reduce the tendency to embrittlement.

Experiments on the Arrest of Brittle Cracks in 36-in. Wide Steel Plates. A. A. Wells, P. H. R. Lane and G. Coates. (*Brit. Welding J.*, 1956, **3,** Dec., 554–570). Plates $\frac{3}{8}$in. thick were used and cracks were initiated in plain and composite specimens, welded or riveted, to determine crack-arresting properties. A machine loading up to 600 tons was used and a description is included. Other tests on the same steels are reported. The results are discussed at length, the findings being somewhat complex and the relation to service conditions somewhat uncertain.

On the Law of Adhesive Wear. H. P. Bhattacharyya. (*J. Appl. Phys.*, 1956, **27,** June, 661). Burwell and Strang derived a formula for the wear of rubbing steel surfaces as a function of load and distance of travel. A modified formula is suggested which takes account of plastic flow and which agrees with the results of experimental data.—E. E. W.

Surface Film Formation and Metallic Wear. W. Hirst and J. K. Lancaster. (*J. Appl. Phys.*, 1956, **27,** Sept., 1057–1065). Three general types of relationship between wear and sliding distance may exist when a relatively soft metal slides on a harder one, each being associated with the formation of a surface film during sliding. The extent to which these films (oxide, adsorbed boundary lubricant, etc.) prevent intermetallic contact, influences the relationship and in some cases two distinct regimes of wear are obtained with a breakdown in the protective film during the transition period.—E. E. W.

Contribution to the Study of the Anomalies in the Internal Friction of Iron due to the Presence of Nitrogen in Solution. L. Guillet and P. Gence. (*J. Iron Steel Inst.*, 1957, **186,** June, 223–226). [This issue].

A New Apparatus for Measuring the Roughness of Surfaces. M. Pesante. (*Ing. Mecc.*, 1956, **5,** June, 5–8). [In Italian]. A new electronic apparatus is described which permits the direct measurement of many of the parameters which define surface roughness, such as the profile of the centre line average height (CLA), the peak to valley height and the form factor.—M. D. J. B.

The Nature of Mechanically Polished Metal Surfaces. Deformation Produced during Abrasion of 18/8 Type Austenitic Steel. L. E. Samuels and G. R. Wallwork. (*J. Iron Steel Inst.*, 1957, **186,** June, 211–218). [This issue].

Precision Grinding as a Means of Improving Wear Resistance of Metal Surfaces. P. Giustina and G. F. Micheletti. (*6th Internat. Mech. Eng. Congress*, 1956, preprint, A2/7, pp. 14). Methods of estimation of surface roughness are outlined and its relation to mechanical wear discussed.

The " Ploughing " Contribution to Friction. R. T. Spurr. (*Brit. J. Appl. Phys.*, 1956, **7,** July, 260–261). Brass or lead sliding against steel was investigated to distinguish friction due to adhesion from that due to the action of asperities in the harder material. Curves and an expression are given.

Mechanical Properties and Wear Resistance of Gas Cyanided Automobile Parts. A. M. Tarasov and B. A. Stetsenko. (*Avtomobil'naya i Traktornaya Promyshlennost*, 1955, (3), 21–24). Gear teeth and rear axles are considered and cyaniding conditions are given and fatigue or static load tests tabulated. Hardness, case depth and ultimate breaking loads are shown and wear-resistance measured. Gas and liquid cyaniding are compared. Safety precautions are mentioned.

Considerations Affecting the Life of Automative Camshafts and Tappets. M. F. Garwood, D. R. Kinker and J. J. Manganello. (*Trans. Soc. Auto. Eng.*, 1956, **64,** 138–152). Failures in service and an accelerated test method are described. A hardenable cast iron was developed and a heat treatment schedule devised for these parts.

Interrelationship of Design, Lubrication, and Metallurgy in Cam and Tappet Performance. E. B. Etchells, R. F. Thomson, G. H. Robinson and G. K. Malone. (*Trans. Soc. Auto. Eng.*, 1956, **64,** 161–181). Test methods are outlined and worn steel and iron surfaces examined.

Camshaft-Tappet Problems in Ford Overhead-Valve Engines. J. S. Laird, C. L. Stevens and V. L. Iles. (*Trans. Soc. Auto. Eng.*, 1956, **64,** 153–160, 181–184). Metallurgical studies leading to the as-cast alloy-iron camshaft and nitro-carburized tappet are described. Testing is discussed and the performance of a martensitic tappet structure shown.

Cylinder Liner Wear in Marine Diesel Engines. S. Toresson and B. Olsson. (*Brit. C. I. Res. Assoc.*, 1956. Nov. preprint, pp. 13 + 19 fig.). Wear on chromium-plated and Vantit liners with cast iron or chromium plated rings is discussed.

Magnetic Examination for the Detection of Defects in Steel Parts. M. Blanchard. (*Centre Doc. Sidér. Circ. Inform. Tech.* 1956, No. 10, 2031–2038). A review is made of the principal methods used in magnetic crack detection with constant or alternating magnetic fields.—B. G. B.

Magnetic Dispersion and Absorption of Iron between 0–7000 megaHertz. E. Naschke. (*J. Phys. Radium*, 1956, **17,** Apr., 330–337).

The Mechanical and Magnetic Relaxation of α-Iron. A. Ferro and J. Montalenti. (*Met. Ital.*, 1956, **48,** March, 124–128). [In Italian]. The heat of activation and the relaxation time of carbon in solid solution have been measured on iron samples containing impurities (0·02% C; 0·35% Mn; 0·02% Al; Ni negligible) by internal friction and magnetic after-effect (i.e. through the initial permeability variation produced by the magnetization). As a first approximation the authors conclude that there is only one relaxation time, as in the case of pure iron. They also establish that heat of activation and relaxation time of carbon do not depend on the quantity of free carbon or on the magnetic field used for measuring the permeability. Magnetic relaxation, however, is found to be proportional to the free carbon, at least for small concentrations, and may therefore be used to measure the presence of very small quantities of free carbon. (20 references).

Effect of Magnetic Field Strength During Condensation on the Coercivity and Form of Vapour-Deposited Iron. A. J. Griest, J. F. Libsch and G. P. Conard. (*J. Appl. Phys.*, 1956, **27,** Sept., 1022–1024). The size, shape and coercivity of iron particles deposited from vapour on copper surfaces were found to be influenced by the temperature of condensation and the strength of the magnetic field applied during deposition. Line broadening in diffraction patterns was attributed to strain in the as-deposited iron which was sufficient to account for the observed coercivities.—E. E. W.

Contributions to Fundamental Research on Permanent Magnets. H. Fahlenbrach. (*Tech. Mitt. Krupp*, 1956, **14,** Apr., 12–15). An electron micrographical study of Alni 120 in regard to its two phase structure and domain boundaries in the optimum magnetic state is reported. Alnico-400 and BaO and cobalt oxide magnets are also investigated and magnetization curves shown.

Advances in the Field of Permanent-Magnet Materials. H. Fahlenbrach. (*Techn. Mitt. Krupp*, 1956, **14,** Apr., 2–11). The properties and applications of the three groups of permanent magnet materials: Alni-Alnico permanent magnets, oxide magnets and iron-cobalt-vanadium (chromium) alloys are discussed.—L. D. H.

Some Properties of the Coercive Force in Soft Magnetic Materials. D. S. Rodbell and C. P. Bean. (*Phys. Rev.*, 1956, **103,** Aug. 15, 886–895).

Reversibility of the Coercive Force in Alnico 5. M. G. van der Steeg and K. J. de Vos. (*J. Appl. Phys.*, 1956, **27,** Oct., 1150). Explanations are submitted for several phenomena, including the differences in coercive force during ageing, which occur during heat-treatment of Alnico.—E. E. W.

Maximum Energy Product of Crystal-Oriented Polycrystalline Ticonal G (Alnico 5) Magnet Steel. H. Zijlstra. (*J. Appl. Phys.*, 1956, **27,** Oct., 1249–1250). An appreciable improvement in the magnetic properties may be obtained on crystal orientation by casting on a chill plate. This causes columnar crystals to grow perpendicular to the plate.—E. E. W.

Motion of Ferromagnetic Domain Walls in 48 Ni–Fe Tapes. R. W. Cole. (*J. Appl. Phys.*, 1956, **27,** Sept., 1104). As the result of experiments on strips under tension using the method of Sixtus and Tonks, it is suggested that the domain wall has a complex form such as a multiple wedge. A distinction between macro and micro relaxation losses is suggested.

Measurement of Unsymmetrical Alternating Current Magnetization Curves with a Synchronous Counter. F. Stäblein. (*Tech. Mitt. Krupp*, 1956, **14,** Apr., 43–45). The apparatus and its characteristics are described.

The Measurement of the Hysteresis Loops of a Direct Current Magnetized Choke of Hyperm 5T. W. Heister. (*Tech. Mitt. Krupp*, 1956, **14,** Apr., 30–42). Circuits are given and instantaneous measurements discussed. Numerous oscillograph traces are illustrated.

On the Interpretation of Magnetic Torque Reversal. S. Chikazumi. (*J. Phys. Soc. Japan*, 1956, **11,** June, 718–719). The effect in Fe_2NiAl is discussed.

Effect of an Inner Pre-magnetization on the Alternating Current Magnetization Curves of Textured Materials. F.-W. Ackermann and K.-J. Theile. (*Tech. Mitt. Krupp*, 1956, **14,** Apr., 24–28). Various Hyperm materials are investigated and many hysteresis curves are shown and correlated with texture.

Gyromagnetic Ratios of the Iron-Nickel Alloys. G. G. Scott. (*Phys. Rev.*, 1956, **103,** Aug. 1, 561–563). Separate curves for high and low intensity values with composition are found.

How Steel Seams are Detected and Measured. J. R. Gustafson, H. Migel, C. H. Hastings, J. C. Smack, W. A. Black, E. F. Weller, F. W. Chapman, J. M. Callan, A. K. Saltis. (*S.A.E.J.*, 1956, July, 62–67). An article based on a symposium. Magnetic, eddy-current, magnetic particle and ultrasonic methods of inspection are summarized.

Crack Detection in Aircraft Structures. W. Deck. (*J. Roy. Aeronaut. Soc.*, 1956, **60,** Nov., 739–748). A review of penetrant, magnetic, electrical, X-ray, and ultrasonic methods for the detection of internal or external cracks.

Applications of Ultrasonics in Metallurgy and Mechanics. P. Hemardinquer. (*Rév. Gén. Méc.*, 1956, **40,** Feb., 61–65; Sept., 309–314). A comprehensive account is given of principles and uses which are tabulated and then discussed. Gas elimination from cast metal, metal refining, preparation and improvement of alloys, preparation of metal powders, nitridation, effects on magnetic properties, metal cleaning, mineral separations, electrolytic dispersion, electron emission, piercing of brittle materials, and light alloy welding are all considered.

The Physical Principles Underlying the Use of Ultrasonics. L. Bergmann. (*Metalloberfläche*, 1956, **10,** Aug., 225–229). The theoretical background to the use of ultrasonic waves is discussed, and the four main methods of producing ultrasonic vibrations are described.—L. D. H.

Ultrasonic Testing. E. Martin. (*Met. Ital.*, 1956, **48,** June, 261–271). [In Italian]. After describing the nature of ultrasonic testing and how it is carried out, the author reviews the wide range over which this non-destructive method of testing can be applied.—M. D. J. B.

Ultrasonic Flaw Detection. B. R. Byrne. (*J. Inst. Loco. Eng.*, 1956, **46,** (2), 114–170). A complete account of the process is given with special reference to probes and their proper use in testing various locomotive parts. Many points are brought out in discussion.

The Use of the Ultrasonic Reflectoscope for the Non-Destructive Testing of Materials. F. Mazzarelli. (*Ing. Mecc.*, 1956, **5,** June, 29–32). [In Italian]. The author describes new applications of ultrasonics to the non-destructive testing of materials. Branscheid's ultrasonic reflectoscope can be used either as a transmitter or as a reflector of waves. Better results are obtained when it is used in the latter capacity. Special precautions have been taken to ensure the reliable detection of defects.—M. D. J. B.

Principles of Shipyard Radiography. E. J. Duffy. (*Welding Metal Fab.*, 1956, **24,** Dec., 442–446).

Recent Progress in the Inspection of Castings by Gamma Rays. A. Blondel. (*Métaux-Corrosion Indust.*, 1956, **31,** Oct., 396–406). A comprehensive account of the use of radioactive isotopes for the determination of the internal soundness of castings is presented. The relative advantages of ^{60}Co, ^{192}Ir, ^{170}Tl and ^{137}Cs are explained. The influence of metal thickness, energy and distance of source, specimen and film, film characteristics and exposure time on the sensitivity of gamma radiography are considered. (13 references).—B. G. B.

Neutron Diffraction Studies on Iron at High Temperatures.

M. K. Wilkinson and C. G. Shull. (*Phys. Rev.*, 1956, **103,** Aug. 1, 516–524). Measurements up to 1000° C are described to establish magnetic scattering effects through the Curie temperature and in the γ-phase.

Critical Magnetic Scattering of Neutrons by Iron. H. A. Gersch, C. G. Skull and M. K. Wilkinson. (*Phys. Rev.*, 1956, **103,** Aug. 1, 525–534). A theoretical discussion of the data in the previous paper. See preceding abstract.

Neutron Scattering from Iron and Carbon by Time-of-Flight. C. O. Muehlhause, S. D. Bloom, H. E. Wegner and G. N. Glasoe. (*Phys. Rev.*, 1956, **103,** Aug. 1, 720–726).

Some Experiments on the Determination of the Latent Heats of Transition of Titanium and Iron. T. H. Schofield. (*J. Inst. Metals*, 1956, **85,** Oct., 68–69). The latent heats of the $\alpha \rightarrow \beta$ transition in titanium and the $\alpha \rightarrow \gamma$ transition in iron have been determined by a method which depends on the constancy of the products of the rates of heating and the times of transformation, and a knowledge of the specific heats. The result obtained for iron (218 cal/g atom) agrees well with accepted values.—B. G. B.

Surface Tension of Pure Liquid Iron, Cobalt, and Nickel at 1550° C. P. Kozakevitch and G. Urbain. (*J. Iron Steel Inst.*, 1957, **186,** June, 167–173). [This issue].

An Automatically Recording Thermal-Expansion Apparatus. H. J. Kelly and H. M. Harris. (*J. Amer. Ceram. Soc.*, 1956, **39,** Oct., 344–348). The apparatus described uses a saturable-core-reactor-controlled furnace, and the sample dilation is sensed by a linear variable differential transformer. Accuracy and flexibility are good. The apparatus is valuable to laboratories making a variety of thermal-expansion measurements.

The Selection of Metals for Airframe Components as Affected by Operation at Elevated Temperatures up to 600° F. M. Tiktinsky. (*Trans. Soc. Auto. Eng.*, 1956, **64,** 131–137).

Apparatus for Oxidation Tests on Steel at High Temperatures, and some Results. G. Lindh. (*6th Internat. Mech. Eng. Congress*, 1956, preprint B/1, pp. 15). A tubular furnace with a controllable gas stream is described for testing small rectangular specimens. Variables are discussed and results on heat-resisting steels given.

High Temperature Rupture-Strength Properties of Chromium-Stainless Steels containing Titanium and Boron. J. Salvaggi and L. A. Yerkovich. (*Trans. Amer. Soc. Metals*, 1956, **49,** Preprint 33). Significant improvements in hot-strength were found for a number of compositions of types 302 and 306 steels having additions of Ti and B. For the nominal 100 hour rupture strength at 1500° F there was an increase from 5000–9000 psi to 18,000–20,000 psi.—E. E. W.

Evidence from Autoradiography for Preferential Self-diffusion of Iron in Grain Boundaries in the α-Phase. C. Leymonic and P. Lacombe. (*Compt. Rend.*, 1956, **242,** Feb., 27, 1175–1177). Armco iron plated with radio-iron, after self-diffusion at 725° and electrolytic polishing is examined micrographically and by autoradiography. It is shown that the rates of diffusion along the boundaries are variable.

Concerning a Systematic Error in Measuring Diffusion Constants. D. S. Tannhauser. (*J. Appl. Phys.*, 1956, **27,** June, 662). The author provides proof that the error is zero when the equation for linear diffusion is used for measuring the diffusion constant in cases where there is a deviation from linear relationship.—E. E. W.

What do We Know About Hydrogen in Steel? C. R. Simcoe. (*Iron Age*, 1956, **178,** Oct. 4, 98–101; Oct. 11, 102–105). A review of the sources, concentrations, and effects of hydrogen in steel.

Effect of Nitrogen on the Mechanical Properties of High-Purity Iron. W. A. Fischer. (*Stahl u. Eisen*, 1956, **76,** Oct. 4, 1304–1305). The author reviews recent publications on the production of high-purity iron and its mechanical properties, mainly the notch impact strength, as a function of the nitrogen content. The nitrogen level of the test pieces varied between 3 and 15×10^{-3}%. The results are presented in graphs. Nitrogen has no effect on the ageing properties of high-purity iron.—T. G.

An Austenitic Alloy for High Temperature Use. R. W. Guard and T. A. Prater. (*Trans. Amer. Soc. Metals*, 1956, **49,** Preprint 32). Experiments have been made on high cobalt austenitic alloys to determine the optimum composition and treatment for an alloy strengthened by precipitation of Ni_3Ti. Detailed processing data are given for the type J-1570.

The Mechanical Properties of Iron–Aluminium Alloys. W. Justusson, V. F. Zackay and E. R. Morgan. (*Trans. Amer. Soc. Metals*, 1956, **49,** Preprint 36). Quenched Fe–Al alloys containing C and Ti exhibited greater ductility than furnace cooled alloys of the same composition and this was accentuated by the addition of $\frac{1}{2}$% Ti. The yield and tensile strengths of both quenched and slowly cooled alloys increased with Al content up to 14% and then fell rapidly. The ductility of all alloys decreased sharply beyond 10% Al.—E. E. W.

Effect of Carbon and Vanadium on the Properties of Shock-Resisting Tool Steel. II. N. Yamanaka, K. Kusaka, A. Tonooka, and M. Hirayama. (*Tetsu to Hagane*, 1956, **42,** Aug., 648–652). [In Japanese]. Studies were made on a steel containing 0·5% C, 1·5% Cr, 2·2% W, and 0·2% V. Increase of carbon content lowered the critical point, M_s point, and the impact strength, and increased the hardenability, yield point, and hardness; generally vanadium had the opposite effects. Full hardness was obtained by oil quenching between 860° and 940° C. The Charpy impact value increased with tempering temperatures up to 200° C, then fell to a minimum between 300° and 350° C.—K. E. J.

Influence of Mn and Mo on the Properties of Mn–Cr Non-deforming Tool Steel. K. Kusaka. (*Tetsu to Hagane*, 1956, **42,** 372–374). [In Japanese]. The effects studied are an increase in Mn content from 0·45% to 2·21%, and of Mo from 0% to 0·60% in steels containing 1·2% of Mn. Values of the A_c and A_r temperatures, and S-curves for the austenite transformation are given. The increases in Jominy hardenability are shown graphically. (10 references).—K. E. J.

Effect of Mo and V Additions on Si–Cr–W Steels for Impact-Resistant Tools. T. Kuno. (*Tetsu to Hagane*, 1956, **42,** Mar., 238–239). [In Japanese]. Some effects on quenching characteristics are reported.—K. E. J.

Effect of Mo, W, and V on the High Temperature Rupture Strength of Ferritic Steel. A. E. Powers. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8,** Oct., Section 2, 1373–1377). A study has been made of the effects of alloying additions of molybdenum, tungsten, and vanadium, singly and in combination, on the high-temperature rupture strength of 0·18% C steel, oil-quenched from above 1150° C and tempered to 250 Brinell hardness. The results are correlated with the effectiveness of the alloying elements in the form of carbides and in solid solution, and the tempering behaviour of the alloys is discussed.—G. F.

An Investigation on Boron-Treated Steels. VI. On the Effects of Boron Addition to Low-Carbon, Low-Alloy Steels. 3. Y. Imai and H. Imai. (*Nippon Kinzoku Gakkai-Si*, 1953, **17,** Aug., 402–407). [In Japanese]. Tests were made on steels containing 0·15–0·20% C, 1·0% Cr, and 0·3–0·7% Cu. Addition of boron had no effect on the normalized steels, but, with most of the steels, the maximum and yield stresses in the hardened and tempered condition were increased. The treatment was more effective than adding manganese. These steels are more suitable as structural or carburizing grades than low Ni-Cr steels.—K. E. J.

Study of Leaded Free Cutting Steels. II. Effect of Lead on the Low Ni–Cr–Mo Steel. H. Ohashi. (*Tetsu to Hagane*, 1956, **42,** Mar., 355–357). [In Japanese]. Results of hardness, ring crushing, and abrasion tests are given for types 8645 and 8645F steels (compositions given); the latter contains approx. 0·15% of lead.—K. E. J.

Study of Leaded Free Cutting Steels. III. Consideration on the Leaded Low Ni–Cr–Mo Steel Applied for Gear Materials. T. Araki. (*Tetsu to Hagane*, 1956, **42,** Mar., 357–360). [In Japanese]. Comparisons are made of mechanical properties after heat treatment, and of results of bending and impact tests of gears, for steel not containing lead (JIS–SCM 21) and those containing lead (8645 + 0·15% Pb; JIS – SNCM 9 + 0·15% Pb).—K. E. J.

Stainless Steel from the User's Point of View. H. J. Wilson. (*Chem. Process Eng.*, 1957, **38,** Jan., 5–10). An account of the properties of stainless steels with reference to their uses in chemical engineering.

Steels for High Temperature Tubes. Study of Their Characteristics. A. Feroci. (*Calore*, 1956, **27,** Jan., 11–18). [In Italian]. The author reviews the development of steels capable of withstanding increasingly high temperatures and greater stresses. The creep of metals at elevated temperatures is studied together with the various factors which influence the metals when hot. Ideal characteristics of heat-resisting materials are discussed and practical limitations are defined.

Typical calculations based on various specifications are given for high-temperature tubes.—M. D. J. B.

Some Properties of Carbon-stabilised Low-carbon Ti Steels. T. Saito. (*Tetsu to Hagane*, 1956, **42**, Mar., 184–186). [In Japanese]. Data are given for a steel containing 0·10% of carbon and 0·64% of titanium; these show the relationship between the hardness and the cold-working ratio, and those between the hardness and the impact value, respectively, and the heating temperature after cold work.—K. E. J.

Corrosion-Resisting Ferrous Metals. G. Bolognesi. (*Rivista Mecc.*, 1955, **6**, July 16, 29–33). [In Italian]. A brief review is given of the classic corrosion-resisting steels, namely: austenitic nickel-chrome steels, austenitic chrome-manganese steels, semi-ferritic or ferritic chrome and chrome-molybdenum steels, and finally martensitic chrome and chrome-molybdenum steels. Some information is also given on stainless steels for very special uses such as are used for containers for acid oxidizing solutions, nitric acid, peroxide, mercury, and copper sulphates.—M. D. J. B.

Study on the Toughness Improvement by the Addition of the Small Amount of Ferro-Titanium in Structural Steel. I, II. T. Saito. (*Tetsu to Hagane*, 1956, **42**, June, 490–495; July, 552–556). [In Japanese]. Titanium readily forms the stable TiS. Work with experimental and practical ingots shows that titanium is more effective than molybdenum and vanadium in increasing toughness in alloy steels, and it decreases brittleness in steels containing manganese. Ferro-titanium is most effective when added to steels containing nickel, manganese or other elements which are soluble in ferrite, and produces fine austenite grains. This treatment is particularly applicable to Ni–Cr–Mo structural steels.

A Study of the Influence of Austenitizing Temperature on Mechanical Properties of a Low Alloyed Cr–V Steel. F. Maratray and G. Delbart. (*Rev. Mét.*, 1956, **53**, Nov., 884–896). The effect of austenitizing temperature between 825 and 975° C on the Jominy hardenability and the mechanical characteristics after oil quenching and tempering has been studied for a 40 CV 4 steel (C = 0·4%, Cr = 1%, V = 0·125%). The properties obtained are correlated with microstructure. The choice of treatment to obtain optimum properties for a specific rupture strength is discussed.—B. G. B.

High Nitrogen Cast Austenitic Steels. J. F. Carlson and V. F. Zackay. (*J. Met.*, 1955, **7**, Oct., 1112–1113). A wrought nickel-free Cr–Mn austenitic has been developed for use at fairly high temperatures. Cr–Mn–Mo–N steels are described and their properties given.

Studies on Mechanical Properties of Timken 16-25-6 at Elevated Temperatures. III. T. Hasegawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 203–204). [In Japanese]. Stress-rupture data are given for the material after hot–cold working, solution heat-treatment, and precipitation hardening.—K. E. J.

Studies on Mechanical Properties of Timken 16-25-6 at Elevated Temperatures. IV. T. Hasegawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 204–206). [In Japanese]. Particulars are given of four compositions tested, rotor wheels (up to 500 mm in diameter) made from them, the heat-treatments, the mechanical properties of specimens from various parts of the wheels, and the stress-rupture strengths of the wheels.—K. E. J.

Properties of Temperature-resisting Austenitic Steels Melted under Reduced Pressure. K. Bungardt and H. Sychrovsky. (*Stahl u. Eisen*, 1956, **76**, Aug. 9, 1040–1049). The authors review metallurgical considerations in the melting of steels under reduced pressures. They discuss the parts played by alloying and foreign matter when melting is carried out in vacuum induction furnaces. The mechanical properties of variously melted heat-resisting austenitic steels are compared.

Study on the High Speed Tools. XVII. H. Hotta and I. Tatsukawa. (*Tetsu to Hagane*, 1956, **42**, June, 495–498). [In Japanese]. In a high-speed steel containing 0·65% C, 15·92% W, 4·30% Cr, 0·76% V, and 2·64% Co, the further the formation of lower bainite progressed in austempering at 200–400° C, the more the secondary hardening occurred in subsequent tempering. Rise of austenitizing temperature in the range 1260–1350° C delayed transformation in the intermediate range. (25 references).—K. E. J.

Sweden Laboratories of the United Steel Companies, Ltd. J. H. Chesters. (*Nature*, 1957, **179**, Feb. 2, 230–233).

METALLOGRAPHY

New Methods and Apparatus for Reflected Light Microscopy. F. Gabler and C. Reichert. (*Radex-Rundschau*, 1956, June-July, 147–152). The possibilities of increasing image contrast in reflected light microscopy are surveyed. A modification of the classical interference microscope which gives images showing a contrast similar and sometimes more detailed than that obtained with phase contrast is described. The difficulties of high and low temperature microscopy are discussed and ways of overcoming them are indicated.

Progress and Limits of Ultramicroscopy. B. V. Borries. (*Radex-Rundschau*, 1956, June-July, 200–225). After a general survey of electron microscopy a detailed account of velocity analysis and diffraction (reflection and transmission) electron microscopy is given including techniques of specimen preparation. The magnetic transmission electron microscope can have a resolution of better than 10 Å and its use in research is established and still increasing.

Direct Viewing of Metal Surface with Emission Electron Microscope. G. Möllenstedt and M. Keller. (*Radex-Rundschau*, 1956, June-July, 153–163). After considering the optics of the emission electron microscope, a method for improving its resolving power is described. In this a beam of rays from a 25 kV discharge in air at reduced pressure is directed at the specimen at an angle of incidence of 20°. Because the electrons emitted from the surface have small initial energies they can be focused to give sharp bright images by an electrostatic or magnetic immersion lens. The resolution obtained experimentally is 500 Å but theoretically a resolution of 200 Å is possible. If the specimen is heated to 150° C to prevent surface contamination contrast is increased markedly. Results are illustrated by photographs of pearlitic steel, cast iron, and sulphide and graphite inclusions.

Two-Dimensional Motion of Idealized Grain Boundaries. W. W. Mullins. (*J. Appl. Phys.*, 1956, **27**, Aug., 900–904). Boundary migration, the curvature rule and area theorem are stated and special solutions derived.

Separation of Supersaturated Mixed Crystals. F. Bollenrath. (*Met. Ital.*, 1956, **48**, April, 141–152). [In Italian]. The author considers the isothermal evolution in time of the separation of supersaturated mixed crystals in certain cast irons, steels and aluminium alloys industrially produced. Ageing curves are examined in so far as they follow Wert and Zener's time law. Evidence is given of the relation between form exponents and temperature in this law. The author establishes experimentally that these exponents are much lower than those obtained by calculation. It is suggested that the probable causes of these differences are the variations in particle numbers, the subdivision of the concentration during precipitation and a difference between diffusion at the grain boundaries and within the grains. Based on experimental observations carried out on an Fe–Cr alloy, a spheroidal cast iron and a number of Al–Cu–Mg alloys with grains of variable size, the author stresses separation phenomena and differences of concentration at the boundaries of the separated particles. Finally the author establishes a dependence between resistance to fatigue and the time law. (13 references).—M. D. J. B.

Stretcher Strain or Lüder Lines in Deep-Drawing Steel Sheets. R. Secco. (*Ing. Mecc.*, 1956, **5**, July, 35–39). [In Italian]. The author describes the appearance of Lüder lines on deep drawing steel sheets and studies the causes which provoke these lines. The relation is established between the appearance of the stretcher-strain markings and the yield phase in the stress–strain diagram. The methods of avoiding these markings are discussed as well as the effects of skin passes and roller levelling. Finally the author discusses the importance of storage temperatures of the steel sheets in respect of their tendency to form Lüder lines.—M. D. J. B.

The Study of Diffusionless Phase Changes in Solid Metals and Alloys. D. S. Lieberman. (*AEC NYO* 3968, 1954, pp. 66; *TIDU List* 572). Metal systems exhibiting such changes were studied, including Fe–Ni. X-Ray, metallographic, goniometric, interference fringe, dilometric, visual and cinematographic methods were used of the effects of stress, temperature, composition and previous history on phenomena related to the transformation. A theory is developed and a graphical method devised for determining the habit plane.

The Zone-Melting Process in the Study of Systems with more than Two Components. F. Mazzoleni. (*Met. Ital.*, 1956, **48**, Sept., 401–405). [In Italian]. The author discusses the possibilities of applying the zone-melting process for the experimental study of metal alloys with two or more components, particularly for the determination of eutectic compositions. (19 references).—M. D. J. B.

High Pressure Polymorphism of Iron. P. W. Bridgman. (*J. Appl. Phys.*, 1956, **27,** June, 659). Comment is made on a paper by Bancroft, Peterson and Minshell on the propagation of shock waves in iron when the shock pattern consists of three discontinuous jumps in pressure. The author looked for evidence of a transition but found none; the resistance decreases smoothly with increasing pressure.—E. E. W.

Transformation Studies of Substitute Special Treatment Steels, Part I—Comparison of Transformation Diagrams. L. F. Spencer and R. H. Raring. (*PB* 111783, 1955, pp. 16; *TIDU List* 579). Enriched modifications of AISI 8727 and 87B27 are considered for conservation of Ni and Cr. Properties are given and tests described.

Transformation Kinetics During Continuous Cooling. J. W. Cahn. (*Acta Met.*, 1956, **4,** Nov., 572–575). It is shown that in transformations involving heterogeneous nucleation, a rule of additivity is often obeyed and that the behaviour of the system in non-isothermal transformation can be calculated from isothermal transformation data.

On the Cooling Transformations in Some 0·40% Carbon Constructional Alloy Steels. D. J. Blickwede and R. C. Hess. (*Trans. Amer. Soc. Metals*, 1956, **49,** Preprint 17). Study of microstructures on interrupted end-quench bars showed that martensite tempers as it forms during cooling and usually causes softening. Formation of martensite is retarded by slow cooling and by prior pro-eutectoid ferrite formation. The latter also retards the bainite reaction. Over a wide range of cooling rates, the temperature at which acicular ferrite starts to form is constant.—E. E. W.

The Influence of Primary Band Spacing and Austenite Grain Size on the Formation of the Ferrite-Pearlite Line Structure. U. Wyss. (*Schweiz. Arch. Wiss. Techn.*, 1956, **22,** Aug., 258–260). The transformation of austenite in the pearlite range in hypereutectoid steels starts by ferrite precipitation along the austenite grain boundaries within the primary bands of dendritic segregation. Therefore the smaller the austenite grain size and the larger the band spacing in comparison, the greater the probability is of ferrite lines being formed.—J. R. P.

On the Existence of a Plastic Deformation in Iron during the α–γ Transformation. P. Lehr. (*Compt. Rend.*, 1956, **242,** Feb. 27, 1172–1175). Differential dilatometric curves are shown in support of a previous hypothesis that plastic deformation occurs at the A_3 point so preventing the reversibility of the curves from being achieved.

A Quantitative Study of the Formation of Austenite and the Solution of Cementite at Different Austenitizing Temperatures for a 1·27% Carbon Steel. G. Molinder. (*Acta Met.*, 1956, **4,** Nov., 565–571). The transformation of a spheroidized 1·27% C steel after rapid heating above the Ac_1 temperature was measured quantitatively using the technique of lineal analysis. It was found that the initial structure remained untransformed at 750° C, and during this incubation period austenite nuclei were formed. At 800°–900° C and following the incubation period at 750° C, the ferrite transformed to austenite with simultaneous rapid solution of cementite. Finally, further solution of cementite occurs until the equilibrium carbon content at the austenitizing temperature is achieved. The thermodynamics of the process are considered.—A. D. H.

Precipitation Reactions in Austenitic Cr–Mn–C–N Stainless Steels. Chi-Mei Hsiao and E. J. Dulis. (*Trans. Amer. Soc. Metals*, 1956, **49,** Preprint 26). The formation of lamellar nodules at grain boundaries and general Widmanstätten precipitation, which cause an increase in hardness, both occur in stainless steels that are solution treated and aged. The former predominates at ageing temperatures above 1500° F while below 1500° F it is retarded and general precipitation occurs. Slow cooling enhances grain boundary formation. The steels remained non-magnetic after all heat-treatments indicating that no austenite to ferrite or martensite transformation had occurred. The grain boundary reaction has been established as a nucleation and growth process.—E. E. W.

Transformation Products in Cold-Worked Austenitic Manganese Steel. R. K. Buhr, S. L. Gertsman and J. Reekie. (*Trans Amer. Soc. Metals*, 1956, **49,** Preprint 28). Electron micrographs have shown that small amounts of ferromagnetic transformation product, probably tempered martensite, are concentrated along the traces of slip planes and at grain boundaries of austenitic manganese steel after cold working.

On the Heterogeneity of Austenite in Steel with 18% Cr and 2, 4, or 6% Ni After Treatments for Carbide Precipitation. P. Bastien and A. Sulmont. (*Compt. Rend.*, 1956, **243,** Dec. 5, 1872–1874). An account of a dilatometric study of carbide precipitation. Complete austenitization at 1000° C followed by rapid cooling to 500°, (rate of cooling from 500–100° is unimportant) produced 80% martensite at 70°. Cooling over a period of hours from 800–500° produced a double transformation. θM_S values are given.

Applications of the Phenomenological Theories of Martensite I–II. J. W. Christian. (*J. Inst. Metals*, 1956, **84,** June, 386–398). A geometrical treatment is given to illustrate in detail the relations between recent phenomenological theories of martensite crystallography. It is shown that according to current theories almost all known martensitic transformations may be reduced to either or both of two types in which the twinning plane, or plane of the lattice invariant strain, is respectively a (110) or a (111) plane of a suitable orthorhombic cell of the product lattice. The detailed predictions of the theories are given in analytical form for the (110) case.

Martensitic Transformation in the Machining of Austenitic Stainless Steel. E. F. Erbin, E. R. Marshall and W. A. Backofen. (*Trans. Amer. Soc. Metals*, 1956, **49,** Preprint 27). Planing and grinding of types 301 and 304 austenitic stainless steels cause transformation of austenite to martensite. The extent under standardized cutting conditions and over a range of temperature was determined quantitatively by an X-ray diffraction technique and was related to the stress, strains and cutting energies.—E. E. W.

Researches on the Kinetics of the Martensite Transformation. J. Philibert. (*Publ. Inst. Rech. Sid.*, 1956, Series A, (139), May, pp. 110). The problem and the nature of the transformation are outlined and the experimental methods described. Two steels high in C and a ferronickel were used and thermal treatments are given, and tests by thermoelectric, dilatometric and magnetic methods outlined. Transformation curves are constructed and the kinetics worked out. A nucleation hypothesis is used. Transformation is then studied near the M_S and M_b points. A theoretical treatment follows and mechanisms of nucleation and stabilization are discussed.

The Effect of Martensite Transformation on Graphitization in Steel. R. Kamensky and A. Tognerova. (*Sbornik vědeckych praci Vysoke školy baňske v Ostravě*, 1955, **1,** (1), 49–55). Effects of hardening temperature, quenching, and repeated hardening on the shape and distribution of graphite flakes in steel during annealing are investigated.

Macrography and Inspection of Metals. I. Gonin and G. de Smet. (*Usine Nouvelle*, 1957, **13,** Jan. 31, 37–38; from *Machine Moderne*, 1956, Apr.). An account of the macroscopic structures of metal parts, sulphur prints, oil quenching effects, magnetoscopic and metalloscopic studies, Forster crack detection, the Ferrotest oscillographic apparatus, magneto-inductive and similar methods, and X-ray examination.

Direct Observation and Recording of Transformations at the Surface of Solid Bodies. R. Mitsche. (*Radex-Rundschau*, 1956, June-July, 197–199). A new direct simple device for direct observation and photographic recording of transformations in solids is described in relation, as an example, to a 2% C, 5% Cr steel at liquid air temperature.

Development of Metallurgical Microscopy. J. C. Wright. (*Metal Treatment and Drop Forging*, 1957, **24,** Jan., 15–20). Mainly historical with brief treatment of recent developments.

Remarks on Quantitative Microscopy. A. Braun. (*Rev. Mét.*, 1955, **52,** Sept., 676–690). Quantitative micrography depends essentially on statistical geometry and the mathematical factors involved are discussed.—B. G. B.

Direct Microscopical and Electronic Diffraction Examination of Metals. R. Castaing. (*Rev. Mét.*, 1955, **52,** Sept., 669–675). The examination of thin test specimens prepared by ionic bombardment is described. This direct method is claimed to be far superior to other methods such as electrolytic polishing.

The Use of the Electron Microscope for Examining Hard Materials. W. Mader. (*Radex-Rundschau*, 1956, June-July, 247–251). The use of electron-microscopy for the determination of grain size and grain form of hard material powders for powder metallurgy is described and compared with light microscopy. Fractographic testing is described and illustrated.

An Electron Mirror Microscope. G. Bartz, G. Weissenberg, and D. Wiskott. (*Radex-Rundschau*, 1956, June-July, 163–172). An electron mirror microscope that enables the direct reproduction of conductive surfaces is described. The experimental value obtained for the resolution of the system is 1000 Å but the theoretical value is 100 Å and means of

improving the actual value are indicated. The future development towards a microscope for secondary emission is described. Screen images illustrated the results.

Carbon Surface Replicas for Electron Microscopy and Electron Diffraction. D. B. Scott and R. W. G. Wyckoff. (*J. Roy. Microscop. Soc.*, 1955, **75**, (4), 217–222). Replicas of rust on steel and of galvanized iron are shown.

Electron Microscope Research of High Strength Constructional Steels. R. Mitsche and A. Legat. (*Radex-Rundschau*, 1956, June-July, 252–257). After a discussion of the relation between microstructure and properties of high tensile weldable structural steels, the advantages of electron microscope examination are considered. In an alloyed structural steel the electron microscope showed changes probably related to changes in physical properties.

Electron Microscope Studies of Steel Fractures. O. Werner and J. Hunger. (*Arch. Eisenhüttenwesen*, 1956, **27**, Oct., 645–656). Results are reported of investigations of impact test specimens of unalloyed structural steels in the normalized and age-hardened state. An interpretation is given of the background structures that occur on the fracture surfaces of brittle crystallite fractures.—L. J. L.

Study of Ferrous Ternary Diagrams in Relation to Magnetic Interactions: Fe–Ni–Al System. U. H. Roesler. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1285–1289). The author has applied Zener's thermodynamic analysis of the γ loop in iron alloys to the Fe–Ni–Al diagram, and obtained two separate parameters describing the influence of the alloying elements on the magnetic transformation range and a hypothetical martensite temperature respectively. An anomalous effect of aluminium on the ferromagnetic characteristics of iron is indicated, and interpreted in terms of short range magnetic order above the Curie point.—G. F.

The Foundations of Metallography. G. Masing. (*Inst. Metals, Monograph and Report Series*, No. 21, 1956, pp. 166). An elementary account of both ferrous and non-ferrous systems.

Metal Whiskers. G. W. Sears and S. S. Brenner. (*Metal Progress*, 1956, **70**, Nov., 85–89). The strength of small metal whiskers is close to the theoretical value; the tensile strength of iron being 1,900,000 lb/in^2. Recent measurements made on metal whiskers are discussed.—B. G. B.

New Reagent to Reveal Micrographically the Austenite Grain in Hardened or Hardened and Tempered Steels. S. Béchet and L. Beaujard. (*Rev. Mét.*, 1955, **52**, Oct., 830–836). A micrographic reagent composed of a saturated aqueous solution of picric acid with an addition of 0·5% Teepol can be used for most hardened or hardened and tempered steels to reveal the austenitic grain boundaries existing after the first γ–α transformation. A number of photomicrographs of specimens etched with this new reagent are reproduced. The reagent is simpler and gives more distinct results than other reagents for this purpose.—B. G. B.

New Sodium Bisulphite Micrographic Reagent for Steel. L. Beaujard and J. Tordeux. (*Rev. Mét.*, 1955, **52**, Sept., 750–756). It is possible with a sodium bisulphite micrographic reagent to reveal in steels physical heterogeneities (grain orientation, twinning deformation lines), segregation of elements in solid solution, and carbide precipitates. The reagent which brings about local variations in colour intensity gives more distinct results than the conventional ones.—B. G. B.

New Etch Spots Leaded Steels. A. E. Gerds and C. W. Melton. (*Iron Age*, 1956, **178**, Aug. 30, 86–87). An etching technique for showing the lead-bearing phases among the microconstituents in steel is described. The staining agent is a mixture of potassium cyanide solution and diphenylthiocarbazone in chloroform.—D. L. C. P.

Electron Metallography of Ferrous Materials. J. Nutting. (*Iron Steel*, 1956, **29**, Nov., 497–501; Dec., 543–545). The author reviews the ever-widening application of the electron microscope to the study of ferrous materials, and illustrates the development of the technique from Mehl's original work in 1941 to the present day. The results of a number of investigations are summarized. (51 references).—G. F.

Study on Ferrite and Cementite with the Electron Microscope. Y. Tanabe. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, Aug., 363–367). [In Japanese]. Ferrite is shown to contain many spherical precipitated particles, most of which are Fe_3Si_2 of average size 550 Å. As the silicon content increases, the size increases, and the particles group with others. They are precipitated in a field of γ-solid solution, and are densest at grain boundaries. Cementite is a combination of Fe_3C and Mn_3C: small quantities of spherical MnSi are precipitated from it. The growth of cementite from pearlite is partially disturbed by Fe_3Si_2 particles.—K. E. J.

Direct Observation of Non-metallic Inclusions in Steel by Electron Microscopy. I. Uchiyama. (*Tetsu to Hagane*, 1956, **42**, Mar., 198–200). [In Japanese]. Details are given of the "extraction replica" technique. The specimen is polished and etched to leave inclusions standing out; it is then covered by a film to form a replica in which the inclusions are embedded. Further etching dissolves more metal, freeing the inclusions from the matrix, and the replica can then be removed for examination of the inclusions.—K. E. J.

Identification of Inclusions. A Study of Deoxidation Products in Iron–Oxygen Melts. F. B. Pickering. (*Iron Steel*, 1957, **30**, Jan., 3–9). Photomicrographs of inclusions of many types are shown and tabulated with suitable spot tests. Deoxidation by Mn, Al, Si, and Ti are considered and the systems Fe–Mn–O_2 etc. resulting are discussed separately.

Discussion of the Hexagonal Epsilon-phase in Vacuum Melted 18/8 Cr–Ni Steels. H. Krainer and E. Krainer. (*Berg-Hüttenmänn. Monatsh.*, 1955, **100**, July/Aug., 247–248). Examination of the structure of vacuum melted 18/8 Cr–Ni steels of low carbon and nitrogen contents after quenching from 1250° C has shown that 3% cold working precipitates an hexagonal epsilon-phase (similar to that of Mn steels) and 10% cold working results in the total precipitation of martensite. X-ray studies have established the parameters of the hexagonal epsilon-phase.

Study on Carbides in Commercial Special Steels by Electrolytic Isolation. II. On Carbides in High-Carbon, High-Chromium Die Steel. T. Sato. (*Tetsu to Hagane*, 1956, **42**, Mar., 239–240). [In Japanese]. Results are given for the amounts of insoluble carbide and the chromium content of the carbide for quenching temp. in the range 800–1050° C, the chromium and carbon contents and the hardness for the same range of quenching temp., and the changes of hardness and chromium content of the precipitated carbide in the range of tempering temp. between 300 and 800° C.—K. E. J.

Carbide Phases Formed on Tempering Hardened Steel. B. A. Apaev. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **107**, (5), 685–688). [In Russian]. The study of carbon steels quenched at 1050° C and then annealed, has shown that above 200° C the phase composition of tempered steel is characterized mainly by the presence of ϵFe_xC with lesser amounts of χFe_xC and Fe_3C. At higher temperatures ϵFe_xC is transformed into cementite and a higher-temperature modification of the intermediate carbide. In the interval 300°–400° C there is a stable equilibrium of χFe_xC, Fe_3C, and an α-solid solution similar to ferrite. At 400° C χFe_xC is rapidly transformed into cementite.—S. I. T.

Study on Carbides in Commercial Steels by Electrolytic Isolation. III. On Carbides in Several Constructional Steels. T. Nishizawa. (*Tetsu to Hagane*, 1956, **42**, Mar., 240–242). [In Japanese]. The amounts and compositions of the carbide and ferrite from six steels of given compositions, in the annealed state, are detailed. The changes in contents of nickel and chromium, chromium and molybdenum, and manganese and silicon, respectively, in the carbide phase are followed as the tempering temp. of three of the steels are varied between 300° and 700° C.—K. E. J.

Studies on the Heavy Inclusions of 18 Cr–8 Ni–Ti Stainless Steel. T. Tanoue. (*Tetsu to Hagane*, 1956, **42**, Mar., 385–387). [In Japanese]. Patterns for the segregation of nitrogen, titanium, and inclusions are shown for three vertical and eight horizontal planes in 1-ton ingots. Results of a segregation examination for titanium, nitrogen, carbon, and oxygen are also given.—K. E. J.

Study on the Micro-cracks of Acm Cementite of the Hypereutectoid Steels. T. Uesugi. (*Tetsu to Hagane*, 1956, **42**, Mar., 191–193). [In Japanese]. The micro-cracks were studied by means of the microstructure of steels as forged and after tensile tests at 700° C, etc.—K. E. J.

Electrolytic Polishing. J. M. McLeod. (*Royal Technical College Metallurgical Club Journal*, 1955–6, (8), 27–32). Steel polishing for metallographic examination is described.

New Method of Electropolishing of Surfaces and its Metallographic Uses. P.-A. Jacquet. (*Compt. Rend.*, 1956, **243**, Dec. 17, 2068–2071). A method of local polishing of general application using an inert, porous insulating coating is described.

A Study of Strain-Free Cutting of Metal Single Crystals. M. Yamamoto and J. Watanabe. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8**, June, 230–242). An etching cutter for single crystals of metals and non-metallic materials is described. Ni, Al, and Bi cut slowly and produce roughened surfaces but Fe, Cu, Sn, and Zn cut rapidly and give smooth surfaces.

χ-Phase (Fe_2C) in Tempering Carbon Steels. M. Okada and Y. Arata. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1956, **6**, Mar., 145–154). The phase has been confirmed by magnetic analysis, X-ray diffraction, and the graphitization test.

The Occurrence of a Cubic Nitride in Aluminium Alloy Steels. W. Koch, C. Ilschner-Gensch, and H. Rohde. (*Arch. Eisenhüttenwesen*, 1956, **27**, Nov., 701–704). Samples of low-carbon steels having 0·005 to 0·75% aluminium were nitrified for 17 hours with ammonia at 600° and were then annealed for 48 hours in an ammonia current at 1000° C. The structure of the nitrided layers was studied under the microscope. Segregations were isolated electrolytically and investigated. Apart from the known nitrides Fe_4N, Fe_2N, and AlN a hitherto unknown phase having a cubic face-centred lattice was discovered.—L. J. L.

New Experiments and Conceptions in the Field of Recrystallization Research. W. G. Burgess. (*Berg-Hüttenmänn. Monatsh.*, 1956, **101**, July, 151–154). A review of the phenomenon of polygonization is given with a definition of recrystallization and consideration of textures produced.

Crystallization Equations. Yu. V. Grdina and L. A. Eliseeva. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **109**, (3), 565–568). [In Russian]. A number of equations are calculated in which temperature, number of centres of crystallization, linear velocity of crystallization, volumes of crystals formed, and other values are involved. These equations are applied to the experimental data relating to the isothermal crystallization of austenite in a eutectoid steel.—S. I. T.

Low Temperature Recrystallization of Metals. R. I. Garber, I. A. Gindin, V. S. Kogan, and B. G. Lazarev. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **110**, (1), 64–66). [In Russian]. This is a study of microstructure changes in iron and nickel mechanically deformed at the temperature of liquid nitrogen, and carried out by means of metallographical and X-ray methods. On reheating of samples to 20° C a recrystallization to a fine grained aggregate was observed in all cases. The formation of microporosity was also observed.—S. I. T.

Sympathetic Nucleation of Ferrite. H. I. Aaronson and C. Wells. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1216–1223). The authors have observed configurations of ferrite crystals in a plain carbon steel which appear to have resulted from nucleation of new crystals at the interphase boundaries of those previously formed. The phenomenon is termed "sympathetic nucleation" and its occurrence is discussed in the light of current nucleation theory.—G. F.

Investigation of the Crystallisation Process in Steel Using Radioactive Tracers. H. R. Bachmann. (*Neue Hütte*, 1956, **1**, Nov., 576–579). An informative abstract is given of a paper by Soviet engineers on the use of ^{32}P as a tracer. The material gives off β-rays; the maximum energy of the particles is 1·71 MeV, and the half life is 14·3 days; it dissolves readily and diffuses well in molten steel and even small quantities can easily be traced. The method would appear to be well suited to the determination of crystallization velocities.

Studies on Austenite Grain Size Control in Iron and Steel, III. Z. Takao, T. Noda, K. Kunii, and H. Takada. (*Suiyokwai-Shi, Trans. Min. Met. Alumni Assoc.*, 1956, **13**, May, 107–109). Effects of Al and relation to alumina and AlN are described.

A Study on the Method for Revealing the Austenite Grain Size in Steel. C. Asada and R. Kadowaki. (*Tetsu to Hagane*. 1956, **42**, June, 476–481). [In Japanese]. A new method is based on appropriate polishing and etching of specimens which are hardened and tempered to the brittle sorbitic structure. If the specimens are rapidly cooled and tempered at 550° C, the austenitic grain boundaries are revealed by an etchant of $FeCl_3$–HCl–alcohol. Dark field illumination is used. Results agree with those by the carburizing method.

Some Aspects of Grain Growth Characteristics of Austenite in Coarse-grained Steels. Y. Masuko. (*Tetsu to Hagane*, 1956, **42**, June, 482–489). [In Japanese]. The investigation was directed to control of grain size for coarse-grained steels for piping required to withstand high temperatures and pressures. Differences in grain size between ladle samples and finished steel are attributed to forging ratio, the reduction of acid-soluble aluminium content, and the distribution of carbides.

The Effect of Alloying Elements on the Austenitic Grain Size of Steel and its Growth. I. A Study by Oxidising Method. M. Kamiyama. (*Tetsu to Hagane*, 1956, **42**, Mar., 179–180). [In Japanese]. Results are given which show the effects of various amounts of Si, C, Mn, and Ni on the austenitic grain size at 950° and 1000° C.—K. E. J.

The Effect of Alloying Elements on the Austenitic Grain Size of Steel and its Growth. II. A Study by Thermal Etching Method. H. Hirodani. (*Tetsu to Hagane*, 1956, **42**, Mar., 180–182). [In Japanese]. Results are given which show the effects of various amounts of Cr, Mo, W, Co, and P on the austenitic grain size, mostly at 1000° C. These are compared with others obtained by a carburization method.—K. E. J.

Effect of Vanadium on the Austenite Grain Size in Iron and Steel. II. K. Kunii. (*Tetsu to Hagane*, 1956, **42**, Mar., 195–197). [In Japanese]. Quantitative results are given which show the effects of vanadium in decreasing the austenitic grain size and increasing the coarsening temperature in steels containing various quantities of carbon and nitrogen.—K. E. J.

Studies on Duplex Grains of Austenite. I. Effect of Duplex Grain Structures on Properties of Steel. II. Mechanism of Formation of Duplex Grain Structures. Y. Masuko. (*Tetsu to Hagane*, 1956, **42**, Mar., 176–177; 178–179). [In Japanese]. Investigations were made of the degree of duplication and the grain size distribution at various temperatures, and the effects of these structures on such properties as the impact transition characteristics. Results are also given for hardness distributions in the same steel samples tested in the fully-hardened state, and for the influence of heating on the AlN content of the steels. (13 references).—K. E. J.

Effect of Hot Working on Grain Growth Characteristics of Austenite. Y. Masuko. (*Tetsu to Hagane*, 1956, **42**, Mar., 242–244). [In Japanese]. Austenitic grain sizes, and contents of aluminium and AlN, are followed for steels containing 0·40% carbon and for a Cr–Mo steel, as forging ratios vary up to 10 and annealing temp. vary from 850° to 1200° C.

The Effect of Stresses on the Lattice Constant of Austenite. E. Scheil and E. Saftig. (*Arch. Eisenhüttenwesen*, 1957, **28**, Jan., 49–51). Experimental confirmation was sought of the suggestion made by E. Houdremont and O. Krisement, that the lattice constant of austenite is smaller in the presence than in the absence of martensite. For iron–nickel alloys with 30% Ni and 0·25% Mn the change in the lattice constant at an 80% conversion of austenite into martensite was found to be within the margin of error.—L. J. L.

Problems of Metallurgy. Academy of Sciences of the U.S.S.R. Moscow, 1953. **Influence of Carbon in Bonding Strength in the Martensite Lattice.** G. V. Kurdyumov, V. K. Kritskaya, and N. M. Nodia. (117–120). [In Russian]. Cylindrical specimens of steel with carbon contents of 0·08–1·0% C were hardened from the uniform austenite range in 10% sodium hydroxide solution. After removing surface layers, hardness and X-ray investigations were made and deductions drawn on the martensite lattice bonding strength.

The Secondary Growth of Acicular Martensite of Primary Origin in a Steel With 2% C and 5% Cr. R. Mitsche. (*Arch. Eisenhüttenwesen*, 1957, **28**, Jan., 53–55). To determine whether the amount of martensite found in the austenite–martensite conversion is dependent both on the temperature, and on time, the conversion characteristics, at liquid air temperature, of a steel with 2% C and 5% Cr that had first been annealed at 1200° C and then quenched in salt water at about 30° C, have been investigated. It is concluded that the martensite was not formed all at once.—L. J. L.

A Study of Crystal Formation in the Martensite Phase by Means of Microcinematography. A. L. Belinkii. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **110**, (4), 556–558). [In Russian]. Using microcinephotography it was possible to follow the process of formation and growth of martensite crystals in Mn–Ni steel and Cu–Sn bronze.—S. I. T.

Exaggerated Grain Growth. P. Coulomb. (*Metaux–Corrosion–Indust.*, 1956, **31**, Nov., 451–456). The phenomenon of abnormal grain growth in metals is discussed and examples in iron are given. (33 references).—B. G. B.

Researches on Crystal Orientation in Cold Rolled Recrystallized Sheets, with Regard to Carbonyl Iron. H. Weik. (*Met. Ital.*, 1956, **48**, Nov., 494–502). [In Italian]. The author shows that oriented crystallization and low mechanical hardness in carbonyl irons are not necessarily incompatible.

Details are given of the research techniques used and of the experimental results obtained. (28 references).—M. D. J. B.

A Simple Method of Austenite Grain Size Measurement. T. Mitsuhashi and Y. Hosoi. (*J. Mech. Lab.*, 1956, **10**, Sept., 202–205). A microscopical method using an engraved slide is described.

Measurement on Ratio of Elongation of Ferrite Grain. T. Mitsuhashi and Y. Hosoi. (*J. Mech. Lab.*, 1956, **10**, July, 132–135). Two concepts, the counting of grains in a given length and the length of a given number of grains, are developed to study Armco sheet, aluminium-killed sheet and rimmed sheets for deep drawing. The methods are equally accurate and the former is more rapid. Ratios of elongation for the above materials are 2, 2·1, and 1·4.

The Mechanism of Phase Transformations in Metals. Symposium 1955. (*Institute of Metals Monograph and Report Series No.* 18, 1956, pp. 346). **Effects of Nucleation Site upon Precipitate Morphology.** H. I. Aaronson. (47–56). Effects of grain boundary structure are considered. Also, growth from interfaces are discussed and an explanation is proposed in terms of effect of allotriomorph shape on boundary orientation. **Sigma-Phase Nucleation and Other Transformations during Diffusion in the Iron–Chromium System.** H. J. Goldschmidt. (105–119). X-Ray analyses of powder compacts are reported. Rate of solid solution formation is observed, and metastable σ-phase formation at 1100° C. **Martensitic Transformations.** B. A. Bilby, and J. W. Christian. (121–172). A review of available data and of recent theories is presented. Nucleation processes and possible roles of dislocations are also discussed. (166 references). **The Nucleation Problem in Martensite.** M. A. Jaswon. (173–185). The dislocation-source theory is outlined and compared with the embryo theory of Fisher, Hollomon, and Turnbull. (48 references). **Homogeneous versus Heterogeneous Nucleation in the Martensitic Transformation.** L. Kaufman and M. Cohen. (187–191). Determination of M_S points of Fe–Ni alloys suggests homogeneous nucleation to be inoperative. However, their occurrence at low temperatures is in agreement with homogeneous nucleation at preferred sites. **Crystal Geometry of the Austenite–Martensite Transformation.** T. L. Richards and W. T. Roberts. (193–207). **The Bainite Reaction in High-Carbon Steels.** O. Krisement and F. Wever. (253–263). The effect of carbide precipitation in high carbon steels on the bainite reaction is studied. Mechanisms adjacent to growing carbide particles and in austenitic matrices are advanced and supported by various lines of evidence. **The Stabilization of Austenite.** S. G. Glover and T. B. Smith. (265–276). Thermal stabilization in a 1% C, 3% Mn steel is investigated. A temperature lag was produced before transformation began again on continued cooling. It is suggested that stabilization may be associated with the first stage of tempering of martensite. **General Discussion.** (277–342).

Transformation on Heating of Martensite of Thermal Origin in Steels of 18% Cr; 2, 4 or 6% Ni and 0·05% C. P. Bastien and A. Sulmont. (*Compt. Rend.*, 1956, **243**, Dec. 17, 2065–2068). Dilatation measurements are used to show the two-stage transformation of martensite. Two phases form initially, α and γ and α changes to γ by a diffusion-controlled process. Rate of heating has a profound effect on the rates of transformation.

Isothermal and Continuous-cooling Transformation Diagrams. G. Mayer. (*Metal Treatment and Drop Forging*, 1956, **23**, Nov., 451–456; Dec., 495–498). Application to continuous cooling conditions is described and M_S temperatures, structure, and mechanical properties are surveyed and micro-structures shown. The isothermal and continuous cooling diagrams are then compared and the results of end-quenching tests and the limitations of the diagrams are considered.

Recrystallisation Studies of Nickel–Chromium and Iron–Nickel–Chromium Alloys. H. Kofler-Valencak and H. Krainer. (*Arch. Eisenhüttenwesen*, 1956, **27**, Nov., 725–730). The recrystallization of nickel–chromium alloys having 80% Ni and 20% Cr and iron–nickel–chromium alloys having 30% Ni and 20% Cr has been studied in the temperature range between 500° and 1100° C by measuring electrical resistance, tensile strength, and failure load, by observation of recrystallization structure, and by evaluation of Debye-Scherrer diagrams.—L. J. L.

Grain Boundaries and Grain-Boundary Segregation in Ferrous Metals. H.-K. Görlich and H. Schenck. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1479–1486). As the mechanical properties of commercial alloys depend to a large extent on their microstructure, the shape of and segregation at the grain boundaries play an important role. In order to study these the authors prepared thin sections, 20μ thick, and dissolved the metal using chemical and electrolytic methods. The residues were analysed by micro-chemical, X-ray, spectrochemical, and electron-microscopical methods. Very small areas of about 0·5μ were analysed by electron diffraction. The results obtained are presented by diagrams, micrographs, and X-ray patterns.—T. G.

Influence of Magnetic Field on the Precipitation Process of Ferromagnetic Phase in Cu–Fe Alloy (I). T. Mitui. (*J. Phys. Soc. Japan*, 1956, **11**, Aug., 895–896).

Transformation of Ball-bearing Steel. K. Abe. (*Tetsu to Hagane*, 1956, **42**, Mar., 197–198). [In Japanese]. Practical and theoretical continuous cooling transformation curves are compared, and the study of the transformation is augmented by etched microstructures.—K. E. J.

The Importance of Time–Temperature Transformation Diagrams and their Application to Welding Techniques. A. Rose. (*Schweissen u. Schneiden*, 1956, **8**, Nov., 442–449). The iron–carbon phase diagram is discussed. Isotherms of alloy steels are compared. Time–temperature transformation diagrams are developed from which the start of martensite formation during cooling can be determined. The information is used for preventing the tendency to weld cracking.—U. E.

Isothermal Transformation Diagram for a Silicon–Chromium Steel. C. J. Osborn. (*J. Australian Inst. Met.*, 1956, **1**, May, 50–52). Steel of type SAE 9254 with 0·56% C, 0·71% Mn, 1·15% Si, and 0·74% Cr was used to obtain the diagram.

The Formation of Pearlite and Martensite in Hard Manganese Steel. K. Janssen and W. Jellinghaus. (*Arch. Eisenhüttenwesen*, 1956, **27**, Sept., 573–578). Investigations of structure and saturation measurements of steel samples isothermally converted at 400 to 750° and having 1·29% C and 13% Mn are reported. Temperature-magnetization curves for the determination of the martensite point and the carbide Curie point are presented. The determination of the lower temperature limit for carbide segregation from the austenite is discussed.—L. J. L.

The Kinetics of the Formation of Austenite in Unalloyed and Low-alloyed Hypoeutectoid Steels. A. Rose and W. Strassburg. (*Arch. Eisenhüttenwesen*, 1956, **27**, Aug., 513–520). Austenite formation in steels having 0·45%, 0·70%, and 0·30% C, 1·1% Cr, and 0·18% Mo, has been investigated. In isothermal tests austenite is formed from ferritic–pearlitic structures by nucleation and growth. The seeds are formed in pearlite at the contact surfaces of cementite and ferrite lamellæ.—L. J. L.

Representation of Austenite Formation in Sub-eutectoid Steels in Time–Temperature–Solution Diagrams. A. Rose and W. Strassburg. (*Stahl u. Eisen*, 1956, **76**, July 26, 976–983). Three steels that were examined ((i) 0·45% C, (ii) 0·70% C, (iii) 0·30% C, 1·1% Cr, 0·18% Mo respectively) under continuous and isothermal experimental conditions are used to demonstrate the method of showing austenite formation in time–temperature–solution diagrams. The effects of carbon content and of chrome and molybdenum contents on pearlite and ferrite solution, the influence of structural condition, and the dissolution of residual carbide in austenite are among the matters discussed.

Investigation of the Isothermal Changes of Cu–Cr and Ni–Cr-alloyed Cast Iron Containing 0·5% Mo. A. De Sy. (23 *Internationaler Giessereikongress in Düsseldorf. Vorabdruck Vortrag Nr* 115, 1956, pp. 10). TTT-diagrams are given for seven cast irons and the effects of alloying elements on the transformation curves are discussed. Microstructures are shown to be in agreement. Cast iron with Mo and Cu is found suitable for obtaining a bainite–martensite structure of uniform hardness and favourable for obtaining an acicular structure by slow cooling.

Studies on Ball-bearing Steels. V. Solution of the Carbide into Austenite. M. Ueno. (*Tetsu to Hagane*, 1956, **42**, Mar., 256–257). [In Japanese]. For SKF tube (composition given), relationships are shown between the hardness and the holding time at quenching temp. between 800° and 860° C, the cementite content and the same time, and the fracture roughness and the holding time at 800° C.—K. E. J.

Studies on Ball Bearing Steels (VI): X-Ray Determination of Retained Austenite—by Integrated Intensities. M. Ueno,

T. Mitsuhashi, and Y. Nakano. (*J. Mech. Lab.*, 1956, **10**, July, 125–131).

Studies on Ball-bearing Steels. VII. Austenitising Behaviour and Rapid Life Test of SkF, Timken and Home-made Ball-bearing Tube Steels. M. Ueno. (*Tetsu to Hagane*, 1956, **42**, Mar., 260–262). [In Japanese]. Data are given for the chemical compositions; amounts of non-metallic inclusions; the relationships between hardness, cementite content, and quenching temperatures between 780° and 880° C; and a rapid life-testing machine.—K. E. J.

The Influence of the Internal Structure of Austenite Grains on the Solid Solution Strength at High Temperature. G. V. Kurdyumov, E. Z. Kaminskii, and V. M. Rozenberg. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **109**, (1), 85–87). [In Russian]. This is a study of an iron alloy containing 29% Ni and 1% Ti. Martensitic transformation occurred below room temperature and the reverse transformation was completed at 640° C. After casting and forging, samples were heated at 1000° C in vacuum for 8 h, cooled in air, cooled in liquid nitrogen, heated to 800°, 1000°, and 1100° C for 8 h and finally cooled in air. The resulting austenite was subjected to thermal treatment and then studied by means of X-rays, in respect to grain size and strength, the results of this study being discussed.—S. I. T.

Calorimetric Studies of the Kinetics of Martensite Formation. O. Krisement. (*Arch. Eisenhüttenwesen*, 1956, **27**, Nov., 731–742). Martensite formation phenomena have been studied by the Borelius micro-calorimetric method in four unalloyed steels having 0·21, 0·41, 0·58, and 0·79% C from room temperature to 300° C. The austenite content was reduced to 2–3% by cooling in liquid air.—L. J. L.

The Martensitic Transformation in the Iron–Nickel System. L. Kaufman and M. Cohen. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1393–1401). The M_S and A_S temperatures of iron–nickel alloys containing 9·5–33·2% Ni have been determined by means of resistance-temperature curves. The results are incorporated in a thermodynamic treatment of the Fe–Ni system.—G. F.

On the Characteristics of the Bainite Transformation. K. Tsuya. (*J. Mech. Lab.*, 1956, **2**, 20–27). Observations under a hot-stage microscope are described, and isothermal transformation diagrams constructed. Rate of nucleation, cross sections of relief markings, lowering of M_S temperature, and behaviour during step quenching are considered and the findings discussed. It is concluded that bainite is formed by nucleation and a diffusion-limited shear process.

Observation of Bainitic Transformation Recrystallisation and Grain Growth in Steels using a High-temperature Microscope with Ciné Camera. T. Bada. (*Tetsu to Hagane*, 1956, **42**, Mar., 200–201). [In Japanese]. A technique is described in which the specimen is photographed during heat-treatment under vacuum conditions. Results of observations on Ni–Cr–Mo steel, die steels, and mild steel are given.—K. E. J.

Matrix Phase in Lower Bainite and Tempered Martensite. F. E. Werner, B. L. Averbach, and M. Cohen. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 1, 1484). The authors describe an X-ray investigation of the matrix phases in lower bainite and tempered martensite. They show the phases to be dissimilar in structure, the former being body-centred cubic and the latter body-centred tetragonal. The modes of transformation are discussed.—G. F.

Wüstite Decay Below 570° in the Presence of Iron. W. A. Fischer, A. Hoffmann, and Ryusuke Shimada. (*Arch. Eisenhüttenwesen*, 1956, **27**, Aug., 521–529). Wüstite decay has been investigated by dilatometric, radiographic, and microscopical methods, by differential thermal analysis, and by measurement of the electrical resistance as a function of temperature and time, the interpretation of the results on the basis of hole-formation theory is given.—L. J. L.

Phase Transformations in Iron–Platinum Alloys near the Composition Fe_3Pt. A. E. Berkowitz, F. J. Donahoe, A. D. Franklin, and R. P. Steijn. (*Acta Met.*, 1957, **5**, Jan., 1–12).

Study on Spring Materials. H. Hotta. (*Tetsu to Hagane*, 1956, **42**, Mar., 187–188). [In Japanese]. Transformation points and other data are given for a Si–Mn steel and a die steel.—K. E. J.

Study of the Fe–Si Order–Disorder Transformation. F. W. Glaser and W. Ivanick. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1290–1295). The order–disorder transformation in Fe–Si alloys has been studied, and the critical temperature for disorder has been determined and found to be highest for the stoichiometric composition of Fe_3Si. The electrical and thermal conductivity characteristics of the ordered and disordered phases are compared as functions of composition.—G. F.

Effect of Silicon on the Equilibrium of Carbon and Oxygen in Molten Iron Saturated with Carbon. S. Matoba. (*Tetsu to Hagane*, 1956, **42**, Mar., 167–169). [In Japanese]. Results are given for five levels of silicon content between 0 and 5·2%, at 1400°, 1500°, and 1600° C. The effect of carbon on the activity coeff. of oxygen in iron of various analyses at temperatures between 1300° and 1600° C is also demonstrated.

On the Effect of Alloying Elements on the Solubility of Carbon in Molten Iron. I. Fe–C–Xi Ternary Solution. M. Ohtani. (*Tetsu to Hagane*, 1956, **42**, Mar., 169–170). [In Japanese]. Effects are described in the cases when X is N, O, Al, Si, P, S, Ti, V, Cr, Mn, Co, Ni, Cu, Zr, Cb, Mo, Ta, and W. The results are related to the atomic structures of the alloying elements.—K. E. J.

On the Mn–S Equilibrium in the C-saturated Molten Iron. II. M. Inoue. (*Tetsu to Hagane*, 1956, **42**, Mar., 165–166). [In Japanese]. The equilibrium was investigated at temperatures in the range 1200–1500° C. Results are also given for the solubility of carbon and for the activity coeff. of sulphur in Fe–Mn–S melts saturated with sulphur, in the same temperature range.—K. E. J.

On Activities of Cr and C in Molten Fe–Cr–C Alloys. M. Ohtani. (*Tetsu to Hagane*, 1956, **42**, Mar., 291–292). [In Japanese]. Various thermodynamic properties are discussed, and a graph gives iso-activity lines for chromium and carbon at 1540° C.—K. E. J.

On the Activities of Cr and C in Molten Fe–C–Cr Alloys. M. Ohtani. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8A**, Aug., 337–351). The behaviour of chromium oxide in molten slag is also considered and the decarburization limit of the alloys calculated.

Type Determination of Alloy Equilibrium Diagrams in the High Temperature Range by Spectral Analysis. L. S. Palatnik. (*Doklady Akad. Nauk S.S.S.R.*, 1956, **109**, (1), 127–130). [In Russian]. At high temperatures the types of binary thermal diagrams can be determined through the study of selective evaporation by spectroscopic analysis. Formulæ related to temperatures and intensities of spectrum lines are given.

Thermodynamical Consideration on the Deoxidation Limit of Cr-steel with Silicon. H. Sakao. (*Tetsu to Hagane*, 1956, **42**, Mar., 381–383). [In Japanese]. Thermodynamic relations at 1600° and 1650° C are derived, and applied to 16·5% and 18% chromium steel.—K. E. J.

The Equilibrium Diagram of the System Iron–Manganese. A. Hellawell. (*Inst. Metals, Annotated Equilibrium Diagrams, No.* 26, 1956, Oct.).

The Equilibrium Diagram of the System Iron–Vanadium. A. Hellawell. (*Inst. Metals, Annotated Equilibrium Diagrams, No.* 27, 1956, Oct.).

The Equilibrium Diagram of the System Chromium–Iron. A. Hellawell. (*Inst. Metals Annotated Equilibrium Diagrams*, No. 25, 1956, Oct.).

Phase Diagram of Iron–Cobalt–Oxygen System. (I). Experimental Study. S. Iida. (*J. Phys. Soc. Japan*, 1956, **11**, Aug., 846–854). The diagram is established above 900° and extrapolated to lower temperatures assuming exponential diffusion rates of ions in the oxides.

The Density, Magnetic Properties, Young's Modulus and ΔE-effect, and their Changes Due to Quenching in Ferromagnetic Iron–Aluminium Alloys. II. Young's Modulus and the ΔE-effect. M. Yamamoto and S. Taniguchi. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8**, June, 193–204). Superlattice effects are described.

CORROSION

Contribution to the Problem of Rusting of Commercial Iron. A. Königer. (*Giesserei*, 1956, **43**, Aug. 30, 498–505). A description of reactions that take place in homogeneous and heterogeneous systems leads to a definition of a boundary layer and diffusion phenomena. Natural corrosion has been simulated by model tests over a given pH-range. Gravimetric corrosion tests are described in which a typical boundary layer is maintained. Field tests are also described. The experimental results are discussed in theoretical terms.

On the Problem of Studies of Corrosion Properties of Metals. I. Okin. (*Zhur. Priklad. Khim.*, 1956, **29**, (3), 360–369). [In Russian]. The use of diagrams of potential-velocity of

solution of metal and velocity of interaction of medium with electrons for the determination of conditions of passivation of the metal, reactivation of the corrosion process, the velocity of solution of metal and the influence of the presence of the basic aggressive agent and other oxidation and reducing agents on the velocity of the solution of the metal etc., is demonstrated on the system iron–nitric acid.—V. G.

The Relation of Thin Films to Corrosion. T. N. Rhodin. (*Corrosion*, 1956, **12**, Sept., 465–475). Thin oxide films isolated from stainless steels and other ferrous alloys have been studied. Their chemical compositions and structural properties are related to the corrosion behaviour of the parent alloy. Details are given of silicon and molybdenum enrichment in films formed on a silicon-modified stainless steel and of variation of the composition of the film by various corrosive media. The relationship between these variations and the corrosion behaviour of the alloy is demonstrated. The effects of impurities and of carbon are discussed. It is postulated that the presence of heteropoly acids in the film is the key to their corrosion properties.—J. F. S.

The Influence of Surface Character and Boundary Surface Reactions on the Fouling of Ships' Bottoms. (*TIDU*. 4925, 1954, *List* 642). Hardness, grease films, adsorption phenomena, surface charge and coating toxicity are discussed. The latter appears to be of greatest importance.

The Influence of Corrosion on the Mechanical and Electrical Properties of a Steel-Aluminium Cable Carrying 110 kV. P. Butković and A. Lahodny. (*Elektrotehniški Vestnik*, 1956, **24**, (6–8), 199–201). [In Serbo-Croat]. A 6 : 1 aluminium-steel cable of 0·24 cm² cross sectional area corroded during storage in unsuitable surroundings in which it was kept for three years. Alumina and silica were found to be the most important corrosion products. Hardness, elongation, texture and strength were also investigated.—P. F.

The Effect of Iron in Galvanic Zinc Anodes in Sea Water. R. B. Teel and D. B. Anderson. (*Corrosion*, 1956, **12**, July, 343–349). Sharp decreases in the current output of zinc galvanic anodes in sea water are attributed to the increase in the electrical resistance and tenacity of the zinc corrosion product films. By keeping the iron content of the zinc below 0·0015 per cent the type of corrosion product can be altered to make the zinc anodes more efficient.—J. F. S.

Corrosion of Metals by Liquid Fertilizer Solutions. D. C. Vreeland and S. H. Kalin. (*Corrosion*, 1956, **12**, Nov., 569–578). The suitability of aluminium, carbon steel and chromium, and chromium-nickel stainless steels to contain nitrogen fertilizer and complete-mix fertilizer solutions was examined. Partial immersion corrosion tests and small scale service trials showed that aluminium and several chromium and chromium-nickel stainless steels could be used for the nitrogen fertilizers. Only the chromium-nickel stainless steels were suitable for the range of complete-mix fertilizers examined, but carbon steel was satisfactory for one of these.—J. F. S.

Pitting and Cracking. U. R. Evans. (*Chem. Indust.*, 1956, Nov. 10, 1291–1297). A lecture. Starting places of attack, electrochemistry, healing and spreading, patterns on Zn, Fe, Al and Sn, zinc pitting in distilled water, pitting at glide planes and dislocations, intergranular corrosion and weakening and stress corrosion and corrosion fatigue are reviewed. (34 references).

Corrosion Resistance of Wires. Drawn After Galvanizing. J. Teindl and O. Blahož. (*Hutnické Listy*, 1956, **11**, (2), 99–102). Corrosion is discussed and the mechanical properties of the wires given. It is recommended that the zinc bath should contain 0·2–0·3% Al.

Stress-Corrosion Cracking Test. A. W. Dana and W. B. Delong. (*Corrosion*, 1956, **12**, July, 309t–310t). A simple means of investigating the susceptibility of metals to stress-corrosion cracking at elevated temperatures in the presence of chloride is described. The **U**-bend specimen has a heater inside the bend and is inserted in a shaped block of porous insulating material partially immersed in chloride solution.

Weathering Methods for the Evaluation of Organic Coatings. C. Noris. (*6th Internat. Mech. Eng. Congress*, 1956, preprint C4/7, pp. 12). Accelerated tests are reviewed and their limitations shown. A test correlating with a 6-month exposure in Singapore is described.

An Improved Water-drop Corrosion Test. K. S. Rajagopalan and V. P. Khanna. (*J. Sci Indust. Res.*, 1956, **15B**, June, 316–319). Comparison is made between the Baker static water-drop method and a new dynamic method which is described. With the latter reproducible results were obtained for screening corrosion inhibitors.—E. E. W.

Iron in Oil Technique as a Corrosion Control Criterion. R. G. Rydell and W. H. Rodewald. (*Corrosion*, 1956, **12**, June, 271t–276t). The iron suspended in the oil phase of the products can be used as a measure of the corrosiveness of sour oil wells. The effectiveness of inhibitor programmes can be quickly judged by the simple analytical method described. Other methods of estimating the corrosion in oil wells are discussed. The iron-in-oil technique has been compared to long-term corrosion maintenance costs in one group of 19 and another of 95 wells with promising results.—J. F. S.

Magnetic Amplifier-Type Recording Instrument for Electrolysis Survey. M. Tanaka, J. Yamaguchi and Y. Sakurai. (*Corrosion*, 1956, **12**, Nov., 549–552). The circuit, method of construction and performance details are fully described for an instrument designed for continuous recording of pipe-to-soil potentials and currents during cathodic protection surveys. The instrument is said to have good stability, negligible drift and rugged construction. It can be used from an A.C. power source or from batteries.—J. F. S.

Steels and Protective Treatments for Use up to 1000° F. H. J. Noble and W. H. Sharp. (*Trans. Soc. Auto. Eng.*, 1956, **64**, 59–75). Choice of steel is considered with particular reference to the martensitic Cr Steels and their corrosion properties and stress corrosion ranges and protective coatings and the ranges of temperature over which they operate are discussed. Organic coatings and platings are reviewed.

Cathodic Protection of Iron. M. J. Pryor. (*Nature*, 1956, **178**, Dec. 1, 1245–1246). A kinetic mechanism is advanced for iron in chloride solutions.

The Inhibition of Corrosion by Sodium Benzoate. J. H. Kaser. (*Corrosion Prevention and Control*, 1956, **3**, Nov., 37–40). The mechanism of the process is discussed in the light of tracer and electron diffraction studies.

The Cathodic Protection of Metallic Structures in Marine Environments. W. A. Bowen, jun. (*Corrosion*, 1956, **12**, July, 317t–321t). A general survey of the requirements of a good cathodic protection scheme for use in sea water is made, several examples being given. Three methods of demonstrating the effectiveness of a scheme are by weight loss measurements of test coupons, some bonded some not to the protected surface, by photographs and by hydrostone gypsum plaster casts of sample areas; the latter are favoured. Automatic control of current flow can be achieved but more permanent reference half-cells are needed. Marine growth is not reduced by cathodic protection.—J. F. S.

The Protection of Cable Sheathing. Cathodic Protection of Telecommunication Cables. J. Gerrard and J. R. Walters. **The Protection of Buried Power Cables against Corrosion.** J. H. Gosden. (*Chem. Indust.*, 1956, Oct. 13, 1060–1068, 1069–1076).

Inhibiting Corrosion of Steel, Aluminium and Magnesium Intermittently Exposed to Brines. G. E. Best and J. W. McGrew. (*Corrosion*, 1956, **12**, June, 286t–292t). A simple corrosion test cycle in which small metal panels were immersed in sodium or calcium chloride solutions for 15 minutes, dried for 15 minutes and dry for 30 minutes, is described. Brines ranging from 1 to 25% of salt were used with a test duration of 15 days. The influence of sodium chromate and dichromate added to the brine was determined, the former being a more effective inhibitor. Very thorough degreasing was essential for reproducible results.—J. F. S.

The Facts of Corrosion in Britain. (*Jenolite News*, 1956, **8**, April-May, 1–6; June-July, 1–3; Sept.-Oct., 1–3). An account of corrosion on familiar objects with illustrations and estimates of the extent and cost of atmospheric corrosion in this country.

The Case of the Chloride Ions. M. R. Hyslop. (*Metal Progress*, 1956, **70**, Nov., 90–92). The detection of the reason for the failure of a stainless steel storage tank is described. Failure was due to stress corrosion by chloride ions leached out of the insulation around the tank.—B. G. B.

Steel Surface Properties Affect Internal Corrosion Performance of Tin Plate Containers. A. R. Willey, J. L. Krickl, and R. R. Hartwell. (*Corrosion*, 1956, **12**, Sept., 433–440). The factors affecting the corrosion of tin-plate inside tins are reviewed. Two laboratory tests are described for evaluating two recently discovered factors. The "rate of pickling" test and the "iron solution" test measure, respectively, a permanent property of the steel surface arising in the annealing operation ("pickle lag") and an effect due partly to the

nature of the surface immediately prior to electro-tinning and partly to the electro-tinning operation itself. It is suggested that other factors, still unknown, also affect the corrosion resistance of tinplate.—J. F. S.

Some Factors Governing Welfare of Steam Boilers and Other Pressure Vessels. F. Shapley. (*Trans. Liverpool Eng. Soc.*, 1956, **77**, 26–45). Corrosion and cracking are discussed.

The Effects of Contamination by Vanadium and Sodium Compounds on the Air-Corrosion of Stainless Steel. G. W. Cunningham and A. de S. Brasunas. (*Corrosion*, 1956, **12**, Aug., 389–405). The accelerated attack on stainless steels at high temperatures caused by sodium sulphate–vanadium pentoxide contaminants in oil fuel ash is worst at about 20% sodium sulphate/80% vanadium pentoxide. No relation to the melting points of various mixtures was found but the solubility of oxygen was unusually high in the most corrosive mixture. It is postulated that the molten oxide layer acts primarily as an oxygen carrier and a destroyer of protective films. Considerable experimental evidence is given and the previous literature is discussed. Additions of calcium oxide, strontium oxide and carbon were particularly effective in reducing the corrosion but carbon was soon lost by oxidation.

Metallurgy. H. A. Holden. (*Chem. Process Eng.*, 1957, **38**, Jan., 15–18). A review of ferrous and non-ferrous metal developments in chemical engineering. (58 references).

Corrosion of Welded Joints. H. Zitter. (*Schweisstechn.*, 1956, **10**, Sept., 113–117). Several types of corrosive attack in weld seams are investigated. Micrographs are given showing the effect of the wrong type of electrode on corrosion; inter- and trans-crystalline corrosion in an austenitic Cr–Ni steel weld, and stress corrosion. Preventive measures are proposed.

Behaviour of 18–8 Stainless Steel in 2 Normal Boiling Nitric and Sulfuric Acid Mixtures. P. E. Krystow and M. Balicki. (*Corrosion*, 1956, **12**, Sept., 449–454). The austenitic stainless steels when exposed to a range of boiling 2N sulphuric–nitric acid solutions corrode little with high proportions of nitric acid (passive zone) then pass through a transition zone of irregular corrosion and two active zones of substantial corrosion. Corrosion rates in the active and passive zones were as anticipated while the rates in the transition zone were entirely unexpected. A maximum in the corrosion/sulphuric acid concentration curve occurred at a critical concentration. This was attributable to excessive corrosion of the chromium constituent. The use of spectrographic equipment for determining the corrosion rates of individual constituents in alloys is advocated.—J. F. S.

Solubility of Iron in Molten Mixtures of Lithium and Potassium Chlorides and Sodium and Potassium Chlorides. V. P. Kochergin and G. I. Stolyarova. (*Zhur. Priklad. Khim.*, 1956, **29**, (5), 730–733). [In Russian]. The velocity of solution of iron in the molten eutectic of lithium and potassium chlorides and in a low-melting mixture of sodium and potassium chlorides was studied.—V. G.

Action of Molten Lithium, Sodium and Potassium Nitrates on Nickel, Copper, Duralumin and some Steels. E. I. G'urovich. (*Zhur. Priklad. Khim.*, 1956, **29**, (9), 1358–1365). [In Russian]. The action of alkali nitrates on the above metals (stainless steel, heat resisting steel, and carbon steel) was studied at 400, 450, and 500° C. It was found that for a majority of metals two parallel processes are taking place: corrosion and the formation of a film. Some of the films obtained may be of practical importance, as decorative colouring of the metal, or as a method of preparation of the surface for painting.—V. G.

The Acid-Resisting Property of High Chromium Stainless Steels. M. Tagaya and S. Isa. (*Osaka Univ. Fac. Eng. Techn. Rep.*, 1955, **5**, Oct., 433–440). Composition and the effects of Ni and Mo are considered. Chromate inhibition of corrosion by 5% H_2SO_4 is noted.

Variations in Radiation Damage to Metals. C. A. Bruch, W. E. McHugh, and R. W. Hockenbury. (*Trans. Amer. Inst. Min. Met. Eng.*, 1956, **206**; *J. Met.*, 1956, **8**, Oct., Section 2, 1362–1372). The authors compare the radiation damage to a group of metals, including iron and stainless steel, exposed under nearly identical irradiation conditions. The general effect is an increase in strength and electrical resistivity, and decrease in ductility. Factors which appear to influence strongly the magnitude of the property change are the crystal structure and the pre-irradiation value of the property. The theory of radiation damage is discussed.—G. F.

Zinc Anodes for Use in Sea Water. J. T. Crennell and W. C. G. Wheeler. (*J. Appl. Chem.*, 1956, **6**, Oct., 415–421). Traces of iron cause failure of anodes. Aluminium and silicon additions are found to prevent this deleterious effect.

Application of Cathodic Protection to 48 Well Casings and Associated Production Facilities at Waskom Field. G. L. Doremus, W. W. Mach, and J. J. Lawnick. (*Corrosion*, 1956, **12**, Aug., 415–421). The methods which have been used to apply cathodic protection to oil well casing, pipe lines, tank bottoms, and other equipment are described.—J. F. S.

Studies on an Electrochemical Test of Corrosion Resistance. M. Tagaya, M. Hujii, S. Kondo, and T. Horibe. (*Nippon Kinzoku Gakkai-Si*, 1953, **17**, July, 342–345). [In Japanese]. Tests were made on dental alloys, viz. Cr–Ni alloy, 18–8 stainless steel and vitallium specimens were immersed in 1% lactic acid, 0·05% HCl, 1% NaCl or 0·1% Na_2S solution, and measurements were made of weight loss or e.m.f. between them and a $Cu/CuSO_4$ electrode. 18–8 Stainless steels were perfectly passive in the lactic acid solution, but small additions (— 0·5%) of NaCl destroyed passivity. The test is mainly useful in indicating the boundary between active and passive states of chromium alloys.—K. E. J.

A Laboratory Method for the Evaluation of Oil Production Corrosion Inhibitors. D. B. Boies. (*Corrosion*, 1956, **12**, Aug., 371–375). A laboratory screening test for inhibitors used in the oil industry is described. The conditions of test are intended to simulate field conditions and the effects on inhibitor performance of variations in temperature, oil-brine ratio, aromatic content of oil and composition of gas phase can be studied.—J. F. S.

ANALYSIS

Highly Sensitive Carbon Determination with a Conductivity Recording Instrument. W. Koch and H. Malissa. (*Arch. Eisenhüttenwesen.* 1956, **27**, Nov., 695–699). Changes in conductivity of a caustic soda solution in the presence of carbon dioxide are recorded. The kinetics of development of carbon combustion can be traced, all irregularities in combustion being recorded. Only such changes in blank values as occur during combustion affect the results.—L. J. L.

Precise Determination of Small Amounts of Carbon in Iron and Steel. T. Tanoue. (*Tetsu to Hagane*, 1956, **42**, Mar., 364–366). [In Japanese]. The method is based on combustion by oxygen blowing to give CO_2. Tin, electrolytic copper or electrolytic iron may be added to accelerate combustion, and estimates of their carbon contents are given.—K. E. J.

New Rapid Method for Determination of Gaseous Contents in Iron and Steel. I. N. Yoneda and H. Kiiagawa. (*Tetsu to Hagane*, 1956, **42**, Aug., 669–673). [In Japanese]. A "Hydrogenmeter" is described for determining hydrogen by a thermal conductivity method after vacuum extraction in a graphite crucible. 15–25 minutes are required for this method; the errors are a few percent; and the minimum quantity of gas is approx. 0·01 ml.—K. E. J.

Determination of Oxygen in Titanium, Zirconium, Chromium, Vanadium, and Steels by Bromination.—Carbon Reduction Method. M. Codell and G. Norwitz. (*Anal. Chem.*, 1956, **28**, Dec., 2006–2011).

Separation of Iron from Aluminium by Precipitation of Ferric Periodate from Homogeneous Solution. L. Ginsburg, K. Millar, and L. Gordon. (*Anal. Chem.*, 1957, **29**, Jan., 46–48).

Benzenephosphinic Acid as Analytical Reagent. Separation of Ferric Iron from Certain Anions and Cations. J. E. Banks, J. F. Pennell, and D. A. Skoog. (*Anal. Chem.*, 1957, **29**, Jan., 113–116). Separation from Mn, Cd, Ni, Co, As, P, Mg, and alkaline earth metals without interference from citrate, tartrate, oxalate, Cl^- and SO_4^{--} is described. Separation from Zn is fairly adequate. Al, Cr, and V are not separated because of coprecipitation, Cu interferes, and Ti, Mo, W, U, Ce, Zr, Ag, Hg, Sn, and Bi are precipitated by the reagent.

Studies of the Determination of Metals by the Extraction Method with Metal Organic Compounds. XI. Determination of Microamounts of Iron in Al, Mg, Zn and Pb. E. Sudo. (*Sci. Rep. Res. Inst. Tôhoku Univ.*, 1956, **8A**, (5), 375–379). Antipyrin–NH_4CNS is used and extracted with ethyl acetate for colorimetric determination at 470 mμ.

Coprecipitation Studies with Ferric Periodate Precipitated from Homogeneous Solution. L. Gordon and L. Ginsburg. (*Anal. Chem.*, 1957, **29**, Jan., 38–46). Coprecipitation of Al, Yt, and Zn is studied.

Determination of Small Amounts of Cobalt in Steels and

Nickel Alloys by the Isotope Dilution–Anodic Deposition Method. D. Salyer and T. R. Sweet. (*Anal. Chem.*, 1957, **29**, Jan., 2–4). Cobaltinitrite is used.

INDUSTRIAL USES AND APPLICATIONS

High-Strength Cold-Worked Reinforcing Bars Made of Basic-Bessemer Steel. H. Hoff and G. Fischer. (*Stahl. u. Eisen*, 1956, **76**, Nov. 1, 1471–1479). The building industry prefers the use of ribbed reinforcing bars because of the good adhesion to concrete. The ribs act, however, as stress raisers and brittle fracture was experienced even with high-strength steel. It was found that the soft basic-Bessemer steel St.37 fulfils the requirements of special ribbed reinforcing bar according to DIN 1045 if the steel is ribbed longitudinally instead of transversely as is usual, and if cold rolled and tempered and finally heavily twisted. The tempering (480°–550° C) is the most important operation in the manufacturing process as the notch effect due to the presence of the ribs is greatly reduced by recrystallization.—T. G.

New Uses for Steel in Building. P. Peissi. (*Acier, OTUA.*, 1956, June). A review with 36 illustrations in colour, being a lecture to the Assoc. provinciale des Architectes français.

Some Factors Affecting Spring Design. W. R. Berry. (*Wire Ind.*, 1956, **23**, June, 509–510, 522). Tension and helical torsion spring design is outlined.

The Use of Stainless Steel in Curtain Wall Construction. Republic Steel Corporation. (*Eng. Min. Met.*, 1956, **24**, Sept., 127–131). [In English].

The Use in Chemical Engineering of Stainless Steels Other than the 18–10 Type. J. Hochmann. (*Génie Chim.*, 1956, **76**, Oct., 97–105). Mo and Cu additions and austenitic–ferritic Mo–Cu steels are considered and their corrosion resistance under extreme conditions. Nitric acid resistance of 25/20 low C–low Si steel is mentioned and nickel-free ferritic and chrome–nickel–manganese replacement steels are dealt with.

Materials for Atomic Energy Plant Construction. O. Rüdiger. (*Stahl u. Eisen*, 1956, **76**, Sept. 6, 1153–1160). The nuclear fission of uranium and the preparation of fissile material are mentioned in an introductory note. The materials used in reactors are then reviewed with reference to their production and properties. Among other materials, steel and zirconium are discussed from the point of view of their susceptibility to radiation. The importance of moderator material, cooling medium, and control rods is discussed. Reports on atomic energy plant planned in the U.S.A. are mentioned.

HISTORICAL

Foundry Techniques Amongst the Alchemy Secrets of Alessio of Piedmont. B. Boni. (*Fonderia Ital.*, 1956, **5**, June, 221–230). [In Italian]. The author gives a description of the work of the astronomer, philosopher and theologian Don Alessio of Piedmont in the 16th century. Much information is given on the preparation of foundry sands at that period.

Technology of Ancient Glass and Metal. (*Nature*, 1956, **178**, Dec. 29, 1430–1434). Report of a discussion at the B.A. meeting, Section H, 1956. **Distribution of Metalliferous Ores in the British Isles.** W. G. Fearnsides. **Mining Extraction, Refining and Casting.** F. C. Thompson. Referring mainly to copper. **Fashioning of Metal Artefacts.** H. Maryon. Soldering and welding in the Ancient World is reviewed. **Studies of Ancient Metalworking Techniques.** H. W. M. Hodges. Bronze-age casting is discussed. **Pattern-Welded Iron Swords.** J. W. Anstee. Experiments to determine the method of production are described. **Scientific Evidence about Metalworking Techniques.** (I) L. Bick. (II) E. Voce. **Scientific Evidence about Provenance of Early Implements.** H. H. Coghlan. Chemical and spectrochemical analyses of artifacts and ores are reported. **Archeological Significance of Metalworking Techniques.** V. G. Childe. **Scientific Evidence from Ancient Artefacts as Related to Conditions of Burial.** T. W. Farrer. Studies of corrosion were discussed.

Researches on Ancient Nails Used in the Horyu-Ji. H. Nishimura and N. Aoki. (*Suiyokwai-Shi, Trans. Min. Met. Alumni Assoc.*, 1956, **13**, May, 91–94). Rather high manganese wrought iron nails from the temple are described.

On the Character and Function of the Iron Library in the Klostergut Paradies at Schaffhausen. E. Müller. (*Stultifera Navis*, 1956, **13**, Oct., 133–141, reprint). An account of the historical collection with illustrations of some of its contents.

The Pre-History and Early History of the Bessemer Process. H. Dickmann. (*Stahl u. Eisen*, 1956, **76**, Aug. 9, 1020–1024). The author describes the work of W. A. Lampadius, a forerunner of Bessemer, and the contribution of G. F. Göransson to the practical development of the Bessemer process.

Henry Bessemer the Metallurgist. E. Schürmann. (*Stahl u. Eisen*, 1956, **76**, Aug. 9, 1013–1020). A biographical review of Bessemer's work is given.

Bessemer and Canada. A. F. G. Cadenhead. (*Canad. Metals*, 1956, **19**, Nov., 16–18). A brief account of the development of iron making in Canada and the influence of Bessemer is presented.—B. G. B.

Stories of the Metal Trade. XIV. The Invention of the Thomas Process. "Proteus." (*Metal Bull.*, 1957, Jan. 29, 19–21).

Problems of Metallurgy. Academy of Sciences of the U.S.S.R. Moscow, 1953. **Academician Ivan Pavlovich Bardin.** Pp. VII–XII. [In Russian]. The part played by I. P. Bardin in the development of the Russian and Soviet iron and steel industry is outlined and some facts on his personal history are given.—S. K.

The History and Development of the Steel Industry on the Pacific Coast. L. J. Soracco. (*Wire and Wire Products*, 1956, **31**, Aug., 894–896, 939). A brief account of the earlier companies in the area.

MISCELLANEOUS

Systematic Care and Maintenance of Wire Ropes. W. M. Halliday. (*Wire Ind.*, 1955, **22**, Dec., 1177–1179).

Armament Metallurgy. H. P. Tardif. (*Canad. Metals*, 1956, **19**, Oct., 42–45). A number of examples of metallurgical problems encountered in armament development is reviewed.

Handmade Sheep Wire Netting. (*Wire Ind.*, 1956, **23**, Mar., 235). A Scottish craft has been revived.

Education and Training in the Iron and Steel Industry. (*British Iron and Steel Federation, 8th Training Conf.* 1956). **A Survey of Present Methods of Training and Education for Engineers.** J. A. Kilby. (7–10). **Works Training of Engineers.** G. S. Bosworth. (11–14). **New Developments in Engineering Education.** F. Bray. (15–18). **The Role of Professional Institutions.** J. A. Pope. (19–23). **Report of Work of Study Groups.** M. O. Bury. (25–28). **The Engineer's Place in Future Developments.** W. M. Larke. (29–32).

Problems of Metallurgy. Academy of Sciences of the U.S.S.R. Moscow, 1953. **Development of Technology and Labour Productivity in Ferrous Metallurgy.** S. G. Strumilin. (465–481). [In Russian]. In 1704 the production of pig iron in Russia per man-hour was 6·93 kg, in 1952 in the U.S.S.R. it was 698 kg. This development is analysed and various aspects are compared with achievements abroad.—S. K.

The State of the Application of Analytical Assessment of Work in the Iron and Steel Industry at the End of 1955. H. Euler and E. Blome. (*Stahl u. Eisen*, 1956, **76**, Nov. 15, 1573–1574). In continuation of a previous paper (*ibid.*, 1955, **75**, 641) the authors report that by the end of 1955 the wages of 85% of all wage-earners in the German iron and steel industry were assessed by this method.—T. G.

Auditing in Iron and Steel Works. H. Müller. (*Stahl u. Eisen*, 1956, **76**, Nov. 1, 1486–1493). The auditing and cost accounting in iron and steel works is described in detail.—T. G.

An Example of the Practical Application of the Cost Schedule in the Iron and Steel Industry. J. Bechberger. (*Arch. Eisenhüttenwesen*, 1956, **27**, Sept., 595–606). Budgeting, costing, bookkeeping etc. in a steel works are discussed. Practical examples are given to illustrate the making of entries.—L. J. L.

Recording Performance in the Works. (*BISRA Summary*, 99, pp. 4). A recorder developed by the Plant Engineering Division is described. Punched tape is used.

Accidents in the Iron and Steel Industry in 1954. H. Antoni. (*Stahl u. Eisen*, 1956, **76**, Sept. 6, 1178–1182). A statistical survey is presented. The causes as well as the incidence of accidents are discussed, and the economics of the problem are reviewed. Possible improvement in methods of accident prevention in the future are considered.

Safety and Hygiene in the Iron and Steel Industry. (*PACT*, 1954, **8**, Oct., 367–370; Dec., 440–442; 1955, **9**, Apr., 93–97; Dec., 415–418; 1956, **10**, Feb., 11–13). These are studies by the A.I.B. on accident prevention intended to form the basis of a safety code. They are to be followed by similar studies of O.H. and electric furnace plant, blast furnaces, rolling mills, and coke ovens. Short notes are given, with occasional discussion, as mixers, cupolas, converters, additions to the

charge, casting, dolomite handling, refractories, and slag and wastes. Structures and operations are all dealt with.

Mineralising Solutions that Carry and Deposit Iron and Sulphur. B. S. Butler. (*Min. Eng.*, 1956, **8**, Oct., 1012–1017). Suggestions are made for a general consideration of the formation of mineral deposits, particularly those of iron; this would be made in stages, with reference to the electromotive series of the elements. At high temperatures, sulphur and iron could both combine with oxygen. Iron may precipitate as oxides at high temperatures, and sulphur as the sulphates of Ba, Sr, Ca, and K (alunite). At lower temperatures, precipitation could result from the change from sulphate sulphur to sulphide sulphur, iron precipitating as the sulphide. (28 references).—K. E. J.

The Crystal Structures of the Trifluorides of Iron, Cobalt, Ruthenium, Rhodium, Palladium and Iridium. M. A. Hepworth, K. H. Jack, R. D. Peacock, and G. J. Westland. (*Acta Crystallographica*, 1957, **10**, Jan. 10, 63–69).

BOOK NOTICES

MOTT, N. F. "*Atomic Structure and the Strength of Metals.*" An account for the non-scientist of recent researches aimed at understanding why metals have their characteristic strength and ductility. (The Page-Barbour Lectures for 1956 at the University of Virginia). 8vo, pp. vi + 64. Illustrated. London and New York, 1956: Pergamon Press. (Price 15*s*.).

The three Page-Barbour lectures published in this book are based in part on two Cambridge lectures designed to present some of the ideas of physics to students of the humanities. Attempts to explain science to the non-scientist have been likened to talking Gaelic to a deaf seagull. In the present case, the "Gaelic" is beautifully understandable, and the amount the non-scientist gets from these lectures will depend only on the extent to which he is willing to overcome his own disabilities. It would be interesting to know what his audience made of Professor Mott's lectures, but the readers of the present review will mainly want to know what interest this book has for the scientist.

The first two lectures give a non-mathematical account of dislocations and of the hardening of metals by locking dislocations with impurity atoms, by the stress due to random impurity atoms and by work-hardening. The third lecture describes the evidence for the existence of dislocations, their role in crystal growth and in the properties of metal whiskers.

Even for the specialist, this is interesting reading. For the many metallurgists trained before dislocations came along, who would like a readable account of their significance, these lectures are excellent.

Finally, for those of us regularly asked to recommend a "good little book" that will explain metallurgy to potential schoolboy recruits, these lectures may be useful. "Metals in the Service of Man" has done excellent service in explaining the technology of the subject; the present volume can be recommended for explaining its science.—N. J. PETCH.

CALVO RODES, RAFAEL. "*El Acero: Su Eleccion y Seleccion.*" La. 8vo, pp. xv + 441. Illustrated. Madrid, 1956: Instituto Nacional de Tecnica Aeronautica Esteban Terradas.

The Spanish title of this book "Election and Selection of Steels" needs a word of explanation to the English reader. *Election* refers to the fixing of the optimum composition and heat-treatment to obtain the desired properties. *Selection* is the determination of the optimum combination of properties and quality factor (*e.g.*, maximum permissible amount of impurities).

The book sets out to answer certain basic questions on the selection of steels for specific purposes. Because tensile strength is a fundamental factor in the choice of a steel, the author begins with a general discussion on the causes of rupture and the phenomena of ductility, embrittlement, and fatigue.

Chapters 2 to 10 follow a logical order dealing, in a straightforward manner, with the mechanism of rupture, the iron–carbon diagram, the decomposition of austenite, the effect of alloying elements, the crystallization and the working of steels, heat-treatment principles, hardening and hardenability (the longest chapter in the book), tempering and temper-brittleness, and sundry treatments such as austempering, surface treatments, and nitriding. This first half of the book constitutes "What an Engineer Must Know."

The second part of the book handles more detailed problems of selecting steels from the point of view of the construction engineer. Some specific cases are worked out in detail.

The third and final part of the book (consisting of 147 pages) is made up of appendices which include tables used in the heat-treatment and hardness testing of steels and sections on the determination of theoretical hardenability, the Jominy end-quench test, determination of hardness in relation to a given tempering treatment and the relationship between the mechanical properties of hardened and tempered steels and their carbon contents and hardness. The appendices include also about forty Spanish INTA (National Institute of Aeronautics) steel specifications, each of which carries the INTA number and the Spanish Iron and Steel Institute specification number.

The book carries a bibliography of items familiar enough to British and American readers (except for fifteen Spanish items) but the lack of an alphabetical index would possibly be a drawback to students.—R. SEWELL.

AMERICAN WELDING SOCIETY. "*Resistance Welding: Theory and Use.*" Prepared by the Resistance Welding Committee, American Welding Society. 8vo, pp. ix + 163. Illustrated. New York, 1956: Reinhold Publishing Corp.; Londo : Chapman and Hall, Ltd. (Price 36*s*.).

With the exception of trade manuals on the operation and use of resistance welding machines, few books have been published which contain any adequate summary of the published information on the fundamentals of resistance welding. This is surprising in view of the extensive use which is made of resistance welding throughout industry for the efficient mass production of relatively light fabrications in metal. The present volume, which has been prepared by the Resistance Welding Committee of the American Welding Society, is, therefore, welcome.

Throughout the book the style of writing is colloquial and extremely readable; the chapter containing definitions of resistance welding terms is most useful and the sections on the principles of resistance welding and resistance welding processes and equipment contain much information condensed into a readily accessible form.

The section on control circuits is perhaps a little brief, although it may be argued that this subject could be better dealt with in a separate book. The chapters on welding symbols, weldability of metals, welding quality, and inspection and testing will be of interest and of value to all users of resistance welding processes, although to the uninitiated the mystic signs in the chapter on welding symbols are reminiscent of the Egyptian hieroglyphics in the British Museum.

The experienced resistance welding engineer, however, will search in vain for information on machine settings to facilitate his rapid selection of the optimum welding conditions for a given job, and the book provides no information on resistance welding costs; these subjects, however, perhaps lie outside its scope. There is little in the book to interest the metallurgist who is not directly concerned with welding, and, indeed, some ten pages only are devoted to the metallurgical aspects of weldability; this section, however, although brief, is reasonably adequate, but, of course, far from fundamental. The theory of heat flow, too, is rather skimped and is dealt with in four pages; again, however, the treatment is adequate for the purpose of the book.

The quality of the printing and paper is of the high standard that one has come to accept in American publications, the illustrations are clean and informative and the binding is substantial. There is an accurate index. The price is, perhaps, a little high, but not excessively so for a book which is intended for use by designers, engineers, and operatives and is not really written for students. All users of resistance welding will be grateful to the American Welding Society for collecting together the scattered information on this subject and presenting it in a useful and reliable form.—W. I. PUMPHREY.

ÉVRARD, RENÉ. "*Forges Anciennes.*" La. 8vo, pp. 225. Illustrated. Liège, 1956: Éditions Solédi.

Although the iron industry in Belgium and Luxemburg goes back to Celtic times, there is very little evidence remaining before about the middle of the sixteenth century. Even the more recent examples are rapidly disappearing, and the heart-cry of the author, "In a few years there will hardly remain any material trace of our iron industry in past centuries," will be echoed by all those concerned with the history of iron and steel in Great Britain. The author makes the most pertinent point that it is not in the existing industrial areas that relics of previous activity are to be found. Here they have been wiped out almost completely by subsequent developments and reconstructions, and it is "in the valleys to calm and peaceful" of the tributaries of the Meuse and Moselle that the author has discovered his material. It is far from improbable that a similar exploration of rural Britain would lead to a corresponding result, and the writer of this review came quite by accident on a most interesting old blast-furnace on the shores of Loch Etive.

What the author has attempted to do, and with great success, is to obtain a maximum of photographic evidence of the old iron-working establishments in his area, and since, so far as the technological, as distinct perhaps from the sociological, point of view is concerned, there is probably little essential difference between the state of affairs on the two sides of the Channel, the evidence collected cannot be without direct interest to those in Britain. Taking establishment by establishment, photographs are provided of all that remains of the industrial activity of earlier times. One might have wished for more detailed descriptions and sectional drawings of the more interesting sites and furnaces, but one is grateful for what has been given.

In addition to the purely technical evidence on the iron industry itself, the data collected throw considerable light on the allied engineering techniques of water-wheels, hammers, etc., and the large mill dams excavated to drive the former have in many cases and in the course of time become astonishingly beautiful. The sociological aspect of the industry is not considered directly, but no one can look at the illustrations of the homes of the owners and managers of these forges without realizing the pleasant conditions under which they lived, and incidentally, the quite considerable profits which the industry must have made. Regarding the conditions of the workers less evidence remains, but the book as a whole leaves one with a general impression of a contented and reasonably prosperous community.

Even the most cursory examination of this publication, on which the author is most sincerely to be congratulated, raises the wish that someone would undertake a corresponding survey and census of the rapidly disappearing evidence relating to the industry which remains in Great Britain.

F. C. THOMPSON.

CULLITY, B. D. "*Elements of X-Ray Diffraction.*" (Addison-Wesley Metallurgy Series). 8vo, pp. xiv + 514. Illustrated. Reading, Mass., 1956: Addison-Wesley Publishing Co., Inc.; London: Academic Books, Ltd. (Price 80*s.*).

This lucidly written and well arranged and illustrated book succeeds admirably in its purpose of introducing the student and young laboratory worker the methods and applications of X-ray diffraction, which are presented in a manner calculated to maintain the interest of the reader. It does not devote very much space to the analysis of crystal structures, but deals excellently with the orientation, grain size, and strain type of problem so much the concern of metallurgists and engineers. The stereographic projection is fully explained and frequently employed throughout the book in clear illustrations of diffraction problems. Reciprocal lattice theory is limited, quite properly, to a short but good account in the appendix, which also contains tables of constants necessary for X-ray analysis. The tone of the book is essentially practical, but sufficient theory is given to cover a large field of work, and for the student there are some practical problem questions at the ends of chapters. Those entering the field of metallurgical X-ray work should certainly not miss this book, but many others would also find it very useful.

J. BACKHURST.

RHINES, FREDERICK N. "*Phase Diagrams in Metallurgy: Their Development and Application.*" 8vo, pp. ix + 340. Illustrated. New York, Toronto, London, 1956: McGraw-Hill Book Co., Inc. (Price 90*s.*).

This book is undoubtedly the most detailed and thorough account of metallurgical equilibrium diagrams available. It is well written, attractively produced, and beautifully illustrated. It is concerned almost entirely with the classification and interpretation of phase diagrams, with full reference to the Phase Rule. The treatment is such that the gas phase and the effect of pressure as a variable are considered, and in fact there is a complete chapter on pressure–temperature diagrams.

The chapters on binary systems deal with the subject in an exceedingly complete and interesting way. The reference at a number of stages to diffusion-couple alloying is very appropriate and not usual. However, the really distinctive feature of the book is the careful and detailed exposition of ternary and more complex phase diagrams, of which the first-class drawings and exploded views form an important part.

There is a chapter surveying the techniques used for the determination of equilibrium diagrams. Also, there is a brief consideration of relevant thermodynamics, but why should this be relegated to an appendix? It is a pity that so very little description is given of the nature of the solid phases and the factors governing their formation; the book is not so large that it could not be expanded moderately for the sake of rounding off and completing the subject. Likewise, a selection of, say, a few dozen of the more important and better established diagrams would be a useful addition to the appendices. Nevertheless, the latter remarks are only suggestions for making the book slightly more comprehensive.

This is a valuable treatise on the nature and interpretation of equilibrium diagrams, and there is nothing available which is quite comparable. It is a sound book for students, although naturally only the more advanced will have the need and ability to assimilate fully the treatment of the complex ternary and higher diagram. However, it is this latter aspect which will make the book of such value to practising metallurgists and research workers.

A. R. BAILEY.

"*Gmelins Handbuch der anorganischen Chemie.*" 8. völlig neu bearb. Aufl. System—Nr. 28: "*Calcium.*" Teil B, Lieferung 1. "*Technologie.*" La. 8vo, pp. viii + 264. Illustrated. Weinheim/Bergstrasse, 1956: Verlag Chemie G.m.b.H. (Price, DM. 147.–).

This new volume of "Gmelin" conforms with the familiar pattern. This part deals with the production, properties, and uses of the metal calcium and all its commercially important compounds including the phosphates. About 2½ pages are devoted to basic slag and the number of references is very great; indeed, at first glance, they appear to make up nearly one-third of the text. As usual this part, as a work of reference, is indispensable, though with every volume that appears "Handbuch" becomes more of a misnomer. As the pace of research and publication accelerates the question inevitably arises as to whether a compilation of this nature is worth while, as so much of its contents is necessarily out of date before it appears. At present the answer would be that it is, but this appears to become increasingly difficult to maintain with each edition.

J. G. C.

EINECKE, GUSTAV. "*Die Flussspat-Lagerstatten der Welt.*" La. 8vo, pp. viii + 408. Illustrated. Düsseldorf, 1956: Verlag Stahleisen. (Price DM. 62.–).

Dr. Einecke has compiled, from what appear to be the most recent sources, a very complete account of world deposits of fluorspar and the output from them. Districts are mapped but are treated geographically rather than geologically, and mining methods are scarcely touched upon.

Concentration methods, heavy-medium, flotation, and electrostatic, are outlined in an 18-page section, and the uses of the mineral in 23 pages, of which about 3 cover the iron and steel industry. The book is obviously intended as a work of reference, but it is not clear what sort of question it is intended to answer.—J. G. C.

JOUSSET, J. "*Chimie.*" (Aide-Mémoire Dunod). 66e Édition. Three Volumes. Sm. 8vo, pp. xxviii + 208 + lxiv; v +

255 + lxiv; xxxi + 209 + lxiv. Paris, 1957: Dunod. (Price, each vol. 480 fr.).

These small volumes are to be regarded as the French equivalent of the "Chemist's Year Book" or the "Handbook of Chemistry and Physics." The mathematical supplement (trigonometrical and mensurational formulæ, powers, roots and reciprocals, and trigonometrical ratios (not logarithmic)) is the same in each volume (48 pages). The metals are in Vol. 3, and tables of the principal alloys are given; 24 are given under iron with compositions and melting points, but these are somewhat inadequate. Thus "Acier, Fe 99 C 1, 1430° C" and "Fonte grise, Fe 94, C 3·5 Si 2·5" are typical entries. The volume is completed by tables of minerals and inorganic compounds with properties and lists of qualitative tests for organic and inorganic compounds. Volume I is General, and Vol. II purely Organic. The volumes would be of little interest to the metallurgist and even to the chemist they are not comparable with the English and American works mentioned, although about the same price.—J. G. C.

NEW PUBLICATIONS

AMERICAN IRON AND STEEL INSTITUTE. "*Light Gage Cold-Formed Steel Design Manual.*" 1956 Edition. 8vo, pp. [vii +] 91. Illustrated. New York, 1956: The Institute. (Price $1).

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"*Blasberg Galvaniseur-Handbuch.*" (Lexikon für Korrosionsschutz und moderne Galvanotechnik). Ein in Art eines Wörterbuches zusammengestelltes Nachschlagewerk über alle in der Galvanotechnik auftretenden Fachausdrücke mit ausführlichen Begriffsbestimmungen und Erlauterungen sowie Tafeln über elektrische Kennzahlen, Schichtwachstum galvanischer Niederschläge und mögliche Ursachen von Fehlern beim Galvanisieren. 8vo, pp. 266. Solingen-Merscheid, 1956: Selbstverlag Friedr. Blasberg G.m.b.H. Spezialfabrik für Galvanotechnik. (Price DM. 11.70).

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DE CARLI, FELICE. "*Vita dei Metalli.*" 8vo, pp. xiii + 269. Illustrated. Milan, 1956: Casa Editrice Dr. Francesco Vallardi.

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W. H. R. BIRD, M.A., B.Sc.

WILLIAM HERBERT RICHARD BIRD was born in 1903 at Broadstairs, Kent. He was educated at the Swansea Grammar School and at Jesus College, Oxford. He graduated as B.A. in the Honours School of Natural Science (Chemistry) in 1925, and obtained his M.A. degree in 1928.

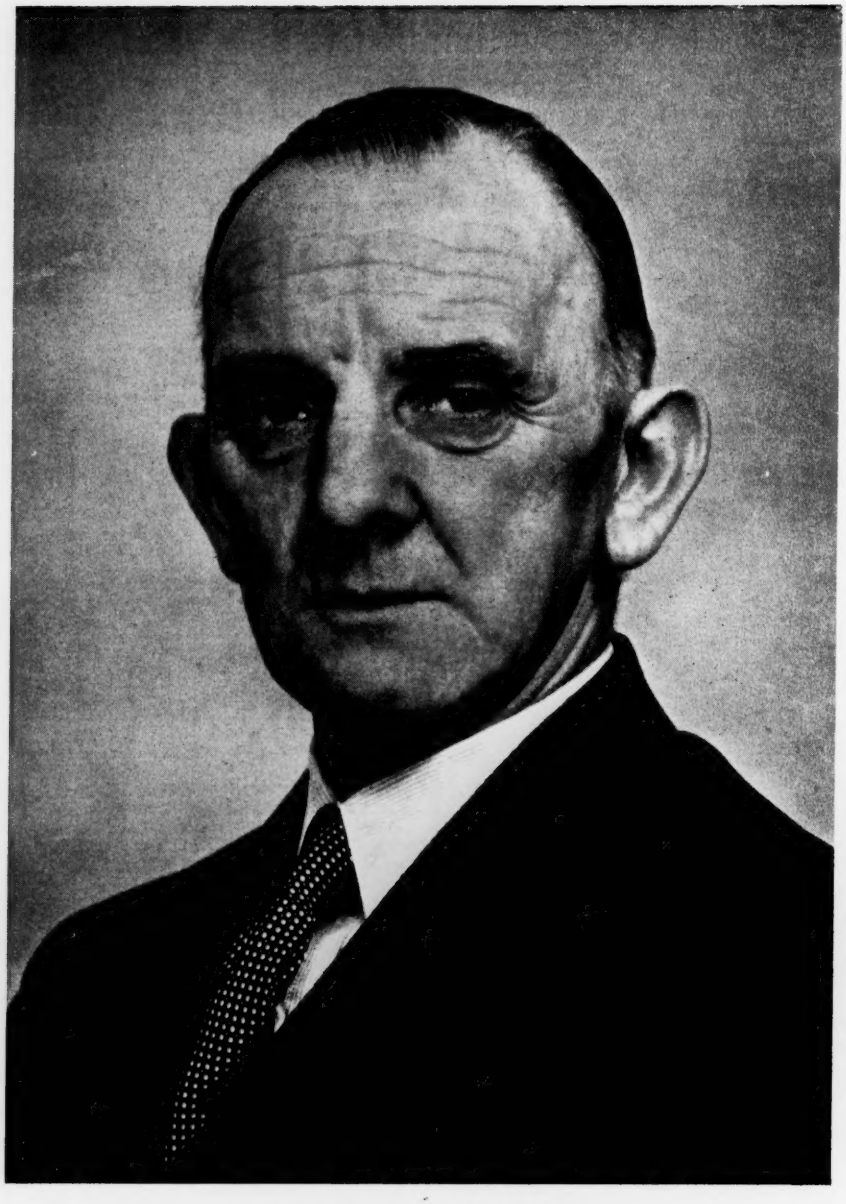
Mr. Bird started his industrial career in 1925 as a research metallurgist at the Grovesend Steel and Tinplate Co., Ltd. (a subsidiary of Richard Thomas and Co., Ltd.). In the following year he completed the external degree of B.Sc. (Special) in Chemistry at London University.

Up to 1938 he was engaged at the various West Wales works of the Richard Thomas combine on a wide variety of research projects in the manufacture of steel sheets, galvanized sheets, and tinplate. For the period 1933–1936, he was seconded with Dr. P. M. Macnair to the Electrolytic Iron Co., Ltd., to assess the manufacture on a large pilot plant of wide continuous electrolytic iron strip.

At the end of 1938, Mr. Bird was transferred to the new strip mill at Ebbw Vale as general metallurgist under the late Mr. R. O. Griffis. On Mr. Griffis's return to the U.S.A. in 1940, Mr. Bird was appointed chief metallurgist at the Ebbw Vale Section of Richard Thomas and Co., Ltd. (subsequently Richard Thomas and Baldwins Ltd.).

Mr. Bird has been a member of The Iron and Steel Institute since 1939. He is a member of several committees of the B.S.I., a member of the Sheet Metal Working Committee of B.I.S.R.A., and a member of the Main Resistance Welding Committee of B.W.R.A. He is chairman of the Sheet Makers' Conference Technical Committee.

He was a member of the Swansea and District Metallurgical Society from 1925–1938, and has been a committee member of the Ebbw Vale Metallurgical Society since 1939. He was Chairman of the latter Society in the 1943–44 session, and President in the 1956–57 session. During this second tenure of office, he served as an Honorary Member of Council of The Iron and Steel Institute.



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Honorary Member of Council 1956–1957